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12 August 1965

MEMORANDUM

From: Professor H. A. Titus, Department of Electrical Engineering
To: Curricular Officer, Aeronautical Engineering Programs

Subj: Confidential Thesis, "Investigation of Optimum Smoothing in
a Track-While-Scan Radar Using Three Dimensional Simulation,"
by LT Richard C. Gentz, USN

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INVESTIGATION OF OPTIMUM SMOOTHING

IN A TRACK-WHILE-SCAN RADAR

USING

THREE DIMENSIONAL SIMULATION ~~(u)~~ (u)

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Richard C. Gentz

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INVESTIGATION OF OPTIMUM SMOOTHING
IN A TRACK-WHILE-SCAN RADAR
USING
THREE DIMENSIONAL SIMULATION *set(u)*

by

Richard C. Gentz

Lieutenant, United States Navy

Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE
IN
AEROELECTRONICS

United States Naval Postgraduate School
Monterey, California

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ABSTRACT

The α, β, γ tracker system of optimal smoothing was investigated in a track-while-scan radar by using three dimensional simulation of various interceptor-target profiles. Random noise was put on all parameters which were not positively defined. This included the target's motion.

The computer program used is designed for carrying on the analysis with other systems so that their performance can be compared with the α, β, γ tracker. A number of representative profiles are listed which should provide a suitable basis for evaluation of any chosen alternate system.

The parameters used in the analysis are similar to those which will be used in the Hughes Aircraft Co. developed AWG-9, Phoenix, Aircraft Missile Control System designed for the F-111B aircraft.

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TABLE OF SYMBOLS

- α : Position smoothing constant.
- β : Velocity smoothing constant
- γ : Acceleration smoothing constant.
- ϵ : Antenna elevation angle.
- η : Antenna azimuth angle.
- Θ : Interceptor Pitch angle.
- λ : General parameter to be smoothed.
- σ : Standard deviation of normally distributed random noise.
- ϕ : Interceptor roll angle.
- ψ : Interceptor heading angle.
- N : North direction cosine.
- E : East direction cosine.
- D : Down direction cosine.
- T : Frame time.

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1. Introduction

The α , β sampled data system has been the most often proposed means of performing the task of optimum smoothing in a track-while-scan radar. This method is particularly attractive since it is very simple. However, in the light of the high performance intercept problems which may be encountered today, especially by a high performance aircraft, it was felt advisable to investigate the capabilities of such a smoothing system in the environment of air-to-air intercepts.

In this analysis the third order system or α , β , γ tracker was considered by using a three dimensional simulation of various interceptor-target profiles. Random noise was placed on all the parameters which were not positively defined. This included the motion of the target.

The computer program used was designed for carrying on the analysis with other systems so that their performance could be compared with that of the α , β , γ tracker.

The parameters used in the analysis were similar to those which will be used in the Hughes Aircraft Company developed AWG-9, Phoenix, Aircraft Missile Control System. This system is currently being developed for use in the F-111B aircraft.

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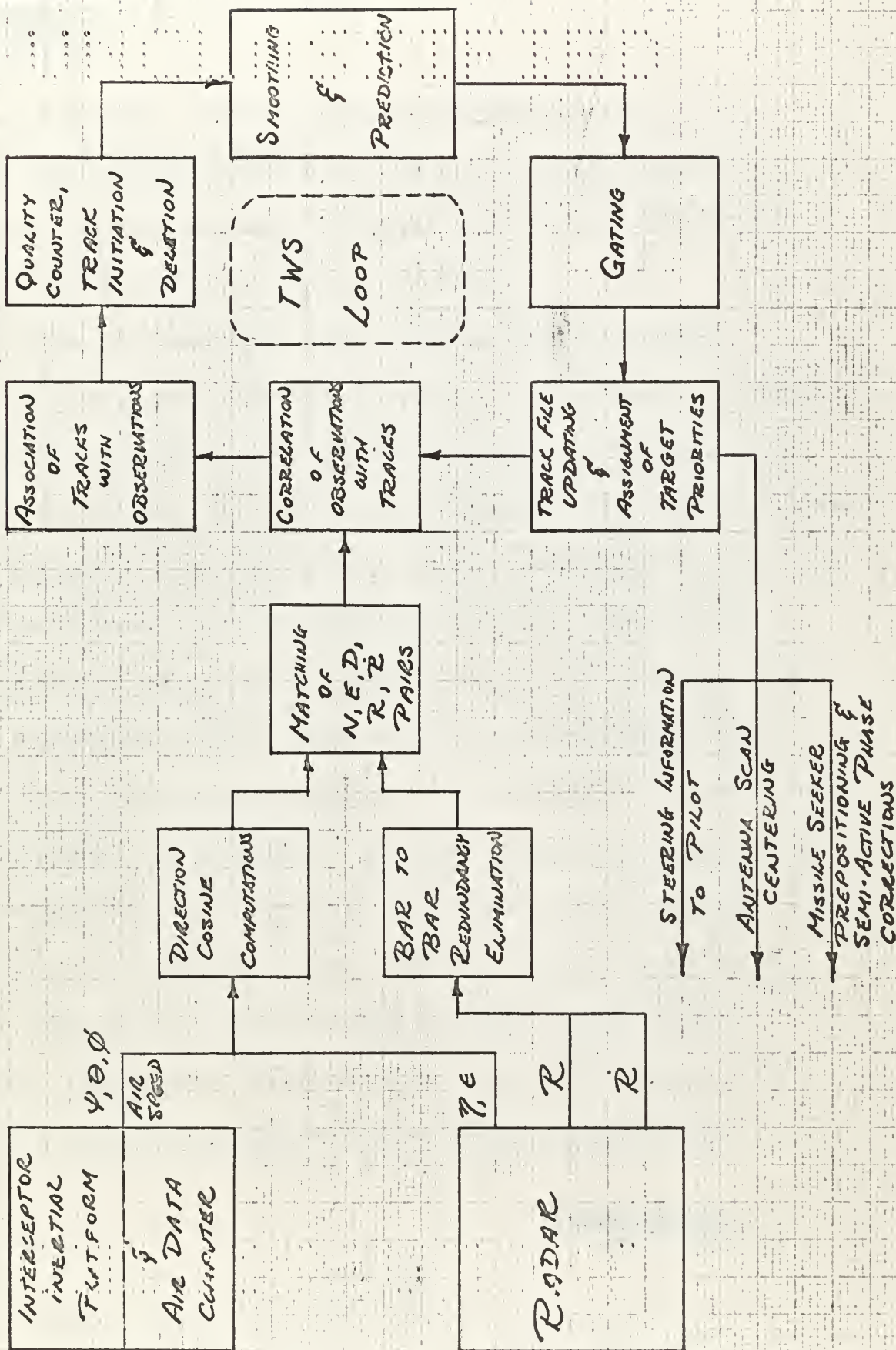
2. Basic System Description

The system considered in the analysis was a pulse doppler radar operating in a track-while-scan mode, TWS. That is, the radar was able to obtain simultaneously at discrete sampling intervals, called frame times, the target's range, range rate, and bearing, in azimuth and elevation, relative to an interceptor's antenna. At the same time the system was also maintaining a track file on a number of other targets at locations spaced over its scan volume.

The heart of a system such as this is the so-called "track-while-scan loop." Fig. 1 is a basic block diagram of this loop.

Prior to entering the TWS loop the raw A to D converted parameters are taken from the output of the radar, and the interceptor's inertial reference platform and air data computer. This information is pre-processed to remove any redundancies caused by picking up the same target on two or more antenna sweeps, called bars. Also the north, east, down direction cosines are computed. These are the direction cosines for a north, east, down axis coordinate system which is fixed to the interceptor. The axes are defined by having the north axis pointing toward true north. The east axis results from the cross product of the

FIG. 1
Track-While-Scan Loop
Block Diagram



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down and north axis. The down axis points towards the earth's local vertical, and is positive downward. Thus an interceptor flying north would have the north axis along the line of sight, the east axis out the right wing and the down axis vertically downward.

The data now enters the "track-while-scan loop." It is first correlated by having the individual observations checked against previous tracks on file in memory. This may result in several observations being linked with one track. These are then associated by having the observations paired by a logic routine with the track which it most closely matches. The next stage initiates new tracks or deletes old tracks, which no longer associate after a quality counter, which rates each track, degenerates to a point such that the track no longer warrants being maintained on file.

The next section and the one which is investigated in this paper is that of smoothing and prediction. The ability of the system to perform all previous and following tasks rests on how well the track is smoothed, i.e., the effect of noise removed, and how well it predicts the target's future motion. This section must be designed to respond quickly to target maneuvers while filtering out the false excursions of the target caused by noise so that future predictions will be as accurate as possible.

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The gating section is next in the loop. It is this section which determines the possible limits of target motion between contacts. It allows for target maneuvers between scans plus approximately 3σ noise. It further provides for expansion in the event of a missed contact. A maximum gate size is imposed which corresponds to a volume which would contain any possible target maneuver that could occur up to the time the track would normally be eliminated by the quality counter due to missed contacts.

The individual track parameters are stored in the track file section to keep it updated. These along with the track locations are used to determine target priorities. The track parameters are also used to determine which observations correlate with the tracks during the correlation phase at the beginning of the loop. The above computations are performed on all tracks at the end of each frame time.

Additional functions which result from the TWS loop computations are the antenna scan center calculations to keep the pattern centroid located in the center of the incoming raids, the steering information to the pilot to allow him to maneuver as necessary to keep the radar within its gimbal limits, prelaunch information to the missile so that its seeker head is oriented in the proper position at the beginning of its semi-active phase,

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~~CONFIDENTIAL~~ and midcourse maneuver corrections to the missile during flight.

It is readily apparent that the system must be optimized to the highest possible degree in light of the high relative speeds encountered and the number of targets to be tracked. At the same time it is extremely important that computations remain relatively simple to maintain reliability and to keep computational time and storage space to a minimum.

The ability of the system to meet these criteria lies primarily in the smoothing, prediction and gating sections. It is the former two which are considered in this paper.

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3. System Characteristics

The values of the system performance parameters were derived primarily from the Hughes SYSTEM EVALUATION AND ANALYSIS REPORT, SEAR, $\angle 1 \angle$. Where possible these parameters have been crossed checked with other company internal documents, or by conversations directly with company engineers. The following parameters and assumptions are those which were used in the simulation.

It was assumed that the interceptor would have an on station Mach number of 0.7 at above 36,000 feet. The target's speed was believed to be between Mach 0.4 and 3.0 and its altitude could be between sea level and 80,000 feet.

The general characteristics of the radar were those of a high PRF pulse doppler using linear frequency modulation.

The detection range was 165 n.m. This was defined as the range where S/N was one using the classic radar range equation. It was based on a five square meter target. The radar's probability of detection curve is shown in Fig. 2.

The effect of clutter on detection probabilities was not considered since a large amount of clutter rejection is an inherent advantage of a high PRF pulse doppler radar. This is particularly true over water. In addition

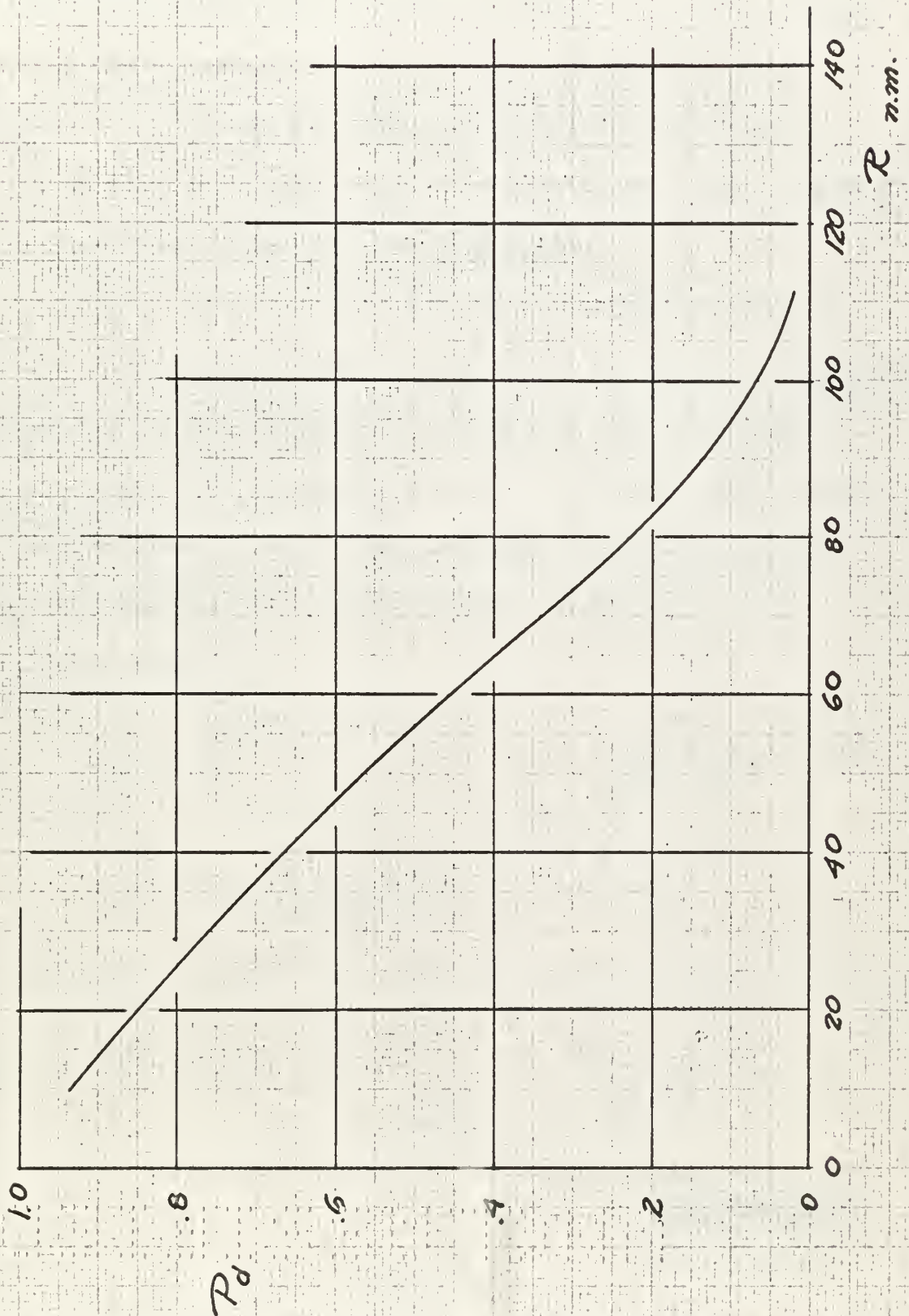
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FIG. 2
Probability of Detection



the system will also have clutter rejection circuitry. Due to the high PRF certain relative velocities may cause periodic loss of signal due to "eclipsing", i.e., target echo returning during pulse transmission. Multiple PRF rates will normally remove this possibility. Thus eclipsing was not considered to effect detection probability.

In the radar, range is measured by taking the difference between two filters in a doppler filter bank that are "rung" on successive FM phases. The spacing of the filters corresponds to five n.m. Since there are 30 filters the range can be measured to 150 n.m. The signal was considered to originate uniformly in plus or minus one-half a filter and terminate normally distributed with a standard deviation of one-third a filter. This is shown in Fig. 3.

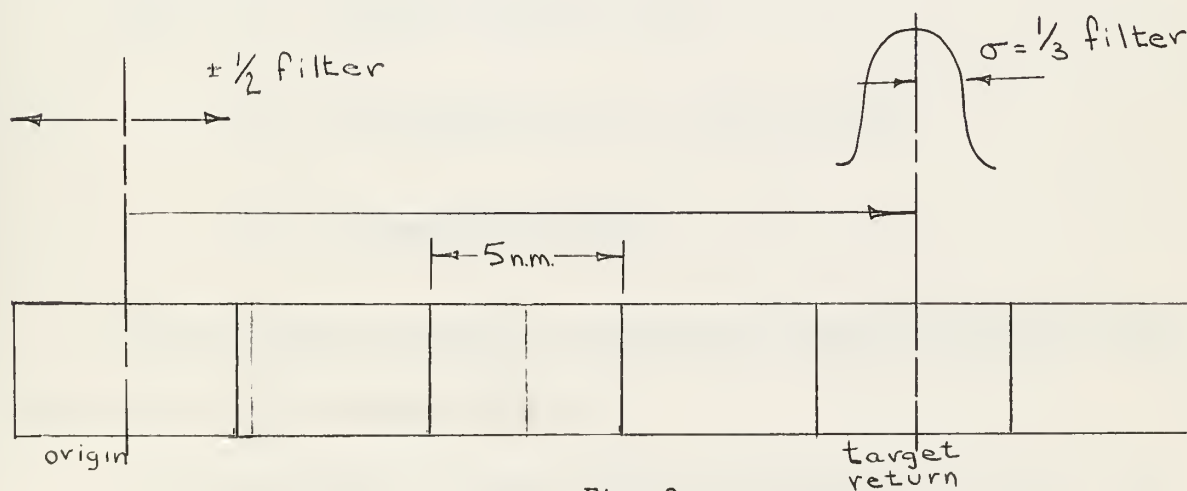


Fig. 3

Probability Distribution of Range Measurement

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Hughes stated that a joint distribution describing these two distributions yielded a normal distribution of zero mean and standard deviation of 1.37 n.m. It was felt that this value was too optimistic and indicated that the distributions were quite dependent, i.e., the covariance was large. The value used for the range standard deviation in this analysis was 2.5 n.m.

Range rate is measured by frequency shift as determined by a doppler filter bank. The filters are spaced 150 cps apart. Thus at X band using the equation given by Skolnik $\sqrt{2}$:

$$V_r = \frac{f_d \lambda}{103} .$$

Where: f_d = doppler frequency shift.

λ = wavelength in cm., 3 cm at X band.

V_r = range rate in knots.

The total number of filters is 768 giving the ability to measure range rates of up to approximately 3250 kts.

It was determined by Hughes that the distribution of the range rate error was normal with zero mean and a standard deviation of two filters, 8.72 kts.

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The scan pattern of the antenna in the TWS mode is either two bar ± 40 deg. or four bar ± 20 deg. The beam separation is 1.32 deg. and the scan rate is 40 deg/sec. It was determined from various sources that the average antenna azimuth error could be considered normally distributed with zero mean and standard deviation of 0.745 deg. Similarly the elevation error had zero mean and standard deviation of 0.86 deg. These values include radome, potentiometer output, and pick off errors. The additional error in elevation is due primarily to the introduction of redundancies caused by picking up the same target on two separate scans.

The smoothing and prediction system which has been proposed by Hughes is the α , β , γ tracker type. The characteristics of this system are considered in the following section.

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4. Smoothing System Discussion

Since computational time and storage space available for smoothing and prediction is quite limited some of the more sophisticated smoothing systems would not at first appear to be suitable for use in the system described. The requirements of the system are reduced somewhat, however, by the fact that the target's capabilities are relatively predictable, but of course, entirely random. For these reasons the most attractive choice is an α, β tracker type of system. Almost any other system that would be acceptable would reduce to a scheme which would use a similar smoothing constant gain technique in any case.

The α, β, γ tracker system is an extension of the α, β tracker to allow for the smoothing of acceleration. As given by Benedict and Bordner $\sqrt{3}$ the variance reduction ratio is optimized by having the velocity constant, β , defined as :

$$\beta = \frac{\alpha^2}{2 - \alpha} .$$

Similarly it was shown by Simpson $\sqrt{4}$ that when acceleration was considered the optimum value of the acceleration smoothing constant, γ , became:

$$\gamma = \frac{2\beta}{\alpha} - (\alpha + \beta) .$$

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Thus if it is possible to define α the smoothing equations become unique.

The proposed equations used for the smoothing and prediction are:

A. Range:

$$\begin{aligned} R_{sn} &= R_{pn} + \alpha (R_n - R_{pn}) \\ \ddot{R}_n &= \ddot{R}_{(n-1)} + \frac{1}{qT} (\dot{R}_n - \dot{R}_{pn}) \\ R_{p(n+1)} &= R_{sn} + T \dot{R}_n + \frac{T^2}{2} \ddot{R}_n \\ \dot{R}_{p(n+1)} &= \dot{R}_n + T \ddot{R}_n \end{aligned}$$

Where:

$$R_n = R_{on} \text{ and } \dot{R}_n = \dot{R}_{on} \text{ if an observation}$$

was received.

$$R_n = R_{pn} \text{ and } \dot{R}_n = \dot{R}_{pn} \text{ if an observation was missed.}$$

$$T = \text{Frame Time} = 2 \pm 0.1 \text{ sec.}$$

q = Number of frame times since last value of range rate was received.

The subscripts are:

n = Frame number.

P = Predicted.

O = Observed.

S = Smoothed

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The value of α for range smoothing as proposed by Hughes was 0.45. Since the standard deviation of range rate was relatively small no smoothing of range rate was necessary so that no β , or γ were required in range smoothing.

B. Direction Cosines:

$$\begin{aligned}\lambda_{sn} &= \lambda_{pn} + \alpha (\lambda_n - \lambda_{pn}) \\ \dot{\lambda}_n &= \dot{\lambda}_{(n-1)} + T \ddot{\lambda}_{(n-1)} + \frac{\beta}{T} (\lambda_n - \lambda_{pn}) \\ \ddot{\lambda}_n &= \ddot{\lambda}_{(n-1)} + \frac{2\gamma}{T^2} (\lambda_n - \lambda_{pn}) \\ \lambda_{p(n+1)} &= \lambda_{sn} + T \dot{\lambda}_n + \frac{T^2}{2} \ddot{\lambda}_n\end{aligned}$$

Where:

$\lambda_n = \lambda_{on}$ if an observation was received.

$\lambda_n = \lambda_{pn}$ if an observation was missed.

λ = general direction cosine being smoothed.

For the North and East direction cosines, N, E, Hughes proposed the smoothing constant values of:

$$\alpha = 0.43$$

$$\beta = 0.120$$

$$\gamma = 0.008.$$

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For the down direction cosine, D , the proposed values were:

$$\alpha = 0.35$$

$$\beta = 0.075$$

$$\gamma = 0.0035.$$

A Z-transform analysis of the α, β Tracker was performed by Sklansky [5]. Basically the system is stable and for a non-maneuvering target there would be no steady state error for α between zero and one. When α is equal to one no smoothing would be performed and raw data would be the output. In a high noise non-maneuvering target condition the smoothing constant would be small and the system response would be slow. For increasingly lower noise the smoothing constant would approach one in the limit. For a maneuvering target the smoothing response must be increased so that a larger value of α is required.

The obvious disadvantage of the α, β Tracker is that there is not a single optimum value of the smoothing constant for all the situations that can be encountered.

The advantage of the system again lies in its simplicity and the small number of computations and amount of storage space required. Also, since β and γ are defined uniquely when α is determined the problem of fixing the constants is reduced somewhat.

5. Simulation

The CDC 1604 computer was used to implement the three dimensional simulation of a single target-interceptor problem. This program was named Three D. The primary aims of the simulation were to provide realistic, flexible and accurate target-interceptor geometries. The pseudo random noise generator, sub routine RNDEV, was used to provide gaussian noise on all parameters that were not positively defined.

A list of symbols and a description of the use of the programs used are contained in Appendices A and B.

The resulting program allowed the target to be positioned initially at any location in the northern half of a north, east, down coordinate system which was ground stabilized at the interceptor's initial location at problem time zero. The target's initial coordinates, maneuver parameters, and maneuver times were then read in by data cards along with the interceptor's heading, altitude, and Mach number. The interceptor's velocity was computed in the program by using the following relation:

$$V_{fps} = \text{Sonic Velocity fps} \times \text{Mach Number.}$$

The variation of the speed of sound with altitude is shown in Fig. 4.

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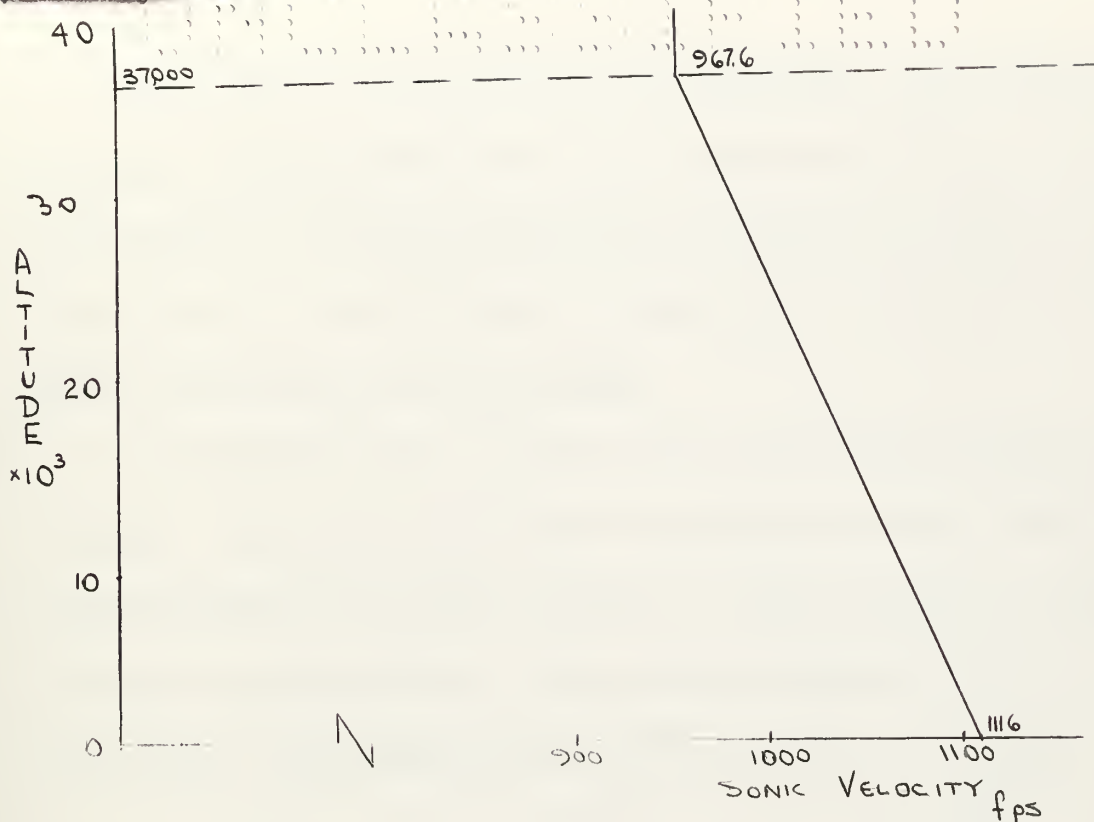


Fig. 4.

Speed of Sound Versus Altitude

No provision was included to maneuver the interceptor since one of the basic assumptions of the system was that the interceptor was continually tracking several targets in widely spaced locations in the radar's scan pattern. It was thus not possible for the pilot to place an individual target in the center of the scan. Also no random noise was used to vary the interceptor's position since the same relative effect was gained by randomly varying the target's velocity components.

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The problem time was taken to be 300 seconds. This allowed a target at Mach 1.5 above 36,000 feet to travel slightly over 70 n.m. in the course of the problem. Since the probability of acquiring and tracking a target beyond 100 n.m. was very low, 100 miles could be considered the range limit in setting up the problem profile.

The target's velocity was also determined by the previously mentioned relations. No provision was made to accelerate the target, but the target would decelerate at the start of its dive. Its final speed was a function of altitude below 10,000 feet. The minimum speed was Mach 1.2, 1340 fps. at sea level. The relations used are shown in Fig. 5. The target was

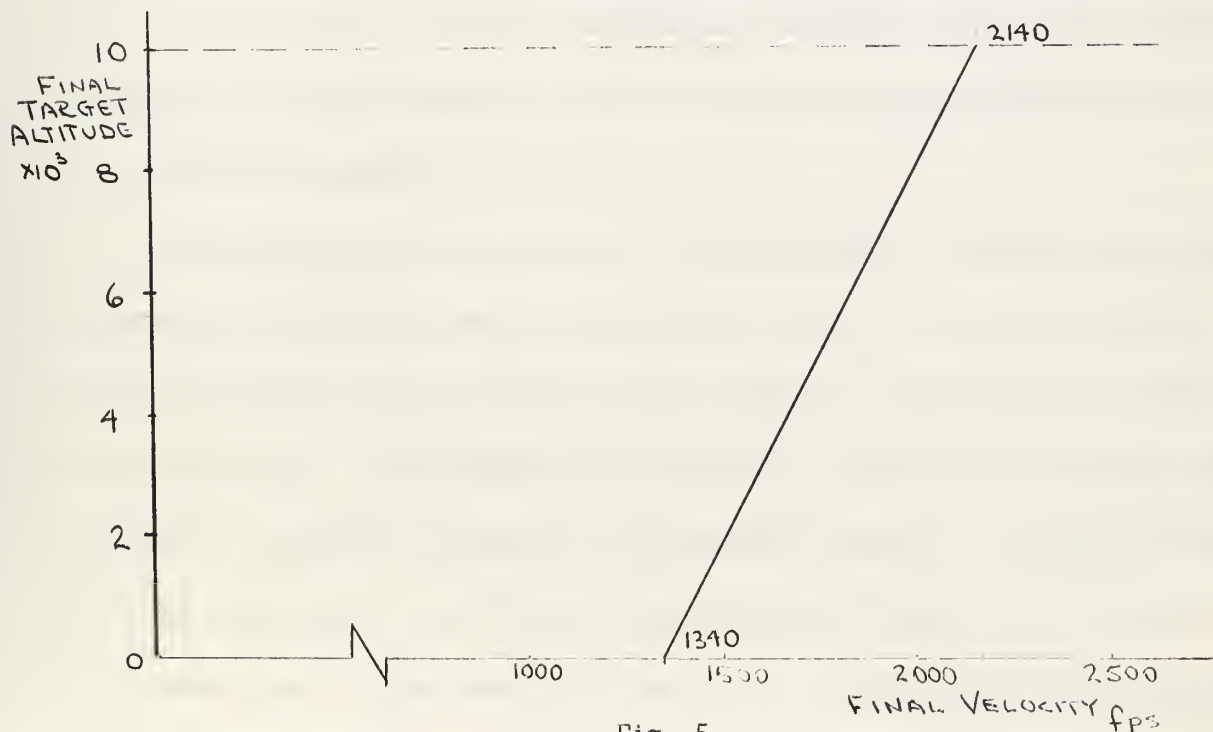


Fig. 5.

Final Target Velocity Below 10,000 Feet :

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programmed to make a 180 degree turn at a programmed time and horizontal turn g load. It would also make a 60 degree dive and pull out at a programmed time, final altitude, positive and negative g factor.

For convenience, distances were read in, in nautical miles, velocities in Mach number, and headings in degrees. The program then converted the values to compatible units of ft., ft./sec., and radians.

The motion of the target was computed by piece-wise-linear integration. Random accelerations having a standard deviation of one-half g for two second periods were imposed. The target's motion was broken down into velocity, VT, along its path of flight, heading angle, AT, and pitch angle, BT. Each component was then related to the distance traveled in each of the coordinate axes in the iteration time and combined with the previous position to give the new target location, XT, YT, ZT.

Every two seconds of problem time the target's coordinates were taken, compared with the interceptor's coordinates XO, YO, ZO and the actual antenna azimuth, ATA, elevation, EPSI, range, R, and range rate, RDOT were computed. If the target had passed out of the limits of the radar beam, + 65 degs. in azimuth and elevation the problem stopped. It should be noted that the antenna does not have a scan volume this large in the track while scan mode, but it does have the capability of positioning its scan anywhere inside these limits.

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The random noise generator was then used to put noise on the radar parameters, ATAE, EPSIE, RE, and RDOT, and the apparent target location having coordinates XTE, YTE, and ZTE, was determined. Since a relatively small number of samples were used the mean, variance and independence of the noise for each of the parameters were checked using an autocorrelation routine. The results of analysis are shown in Table I.

The actual and noisy direction cosines for the three axes were then computed. These were, north direction cosine, DIRN, and DIRNE, east direction cosine, DIRE and DIRE, and down direction cosine, DIRD, and DIRDE.

Knowing the probability of detection of the radar, RNDEV was used to determine a zero-one probability of detection for each frame time. This was done by cross plotting the absolute value of the deviation required, versus range, corresponding to the probability of detection curve, Fig. 2. This was then made piece wise linear and implemented by using IF statements. Thus for each actual range a maximum value of deviation for detection could be determined, if the absolute value of DEV obtained from RNDEV exceeded this value no return for that frame time was assumed. Fig. 6 illustrates the method used.

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TABLE I

AUTOCORRELATION ANALYSIS RESULTS OF PROGRAM
THREE D
(151 SAMPLES)

	Mean	Variance	Largest Value of Autocorrelation
RN 1 Target Acceleration Noise	0.0112	.772	0.1787
RN 2 Target Heading Acceleration Noise	-0.001	1.0636	0.1706
RN 3 Target Pitch Acceleration Noise	-0.1032	0.9585	0.2358
ATA Antenna Azimuth Noise	0.0785	0.9612	0.1717
EPSI Antenna Elevation Noise	0.6308	1.0433	0.1576
R Radar Range Noise	0.1386	0.9938	0.1721
RDOT Radar Range Rate Noise	0.1114	0.9780	-0.1528
PD Radar Probability of Detection Noise	-0.0564	0.9914	-0.1468

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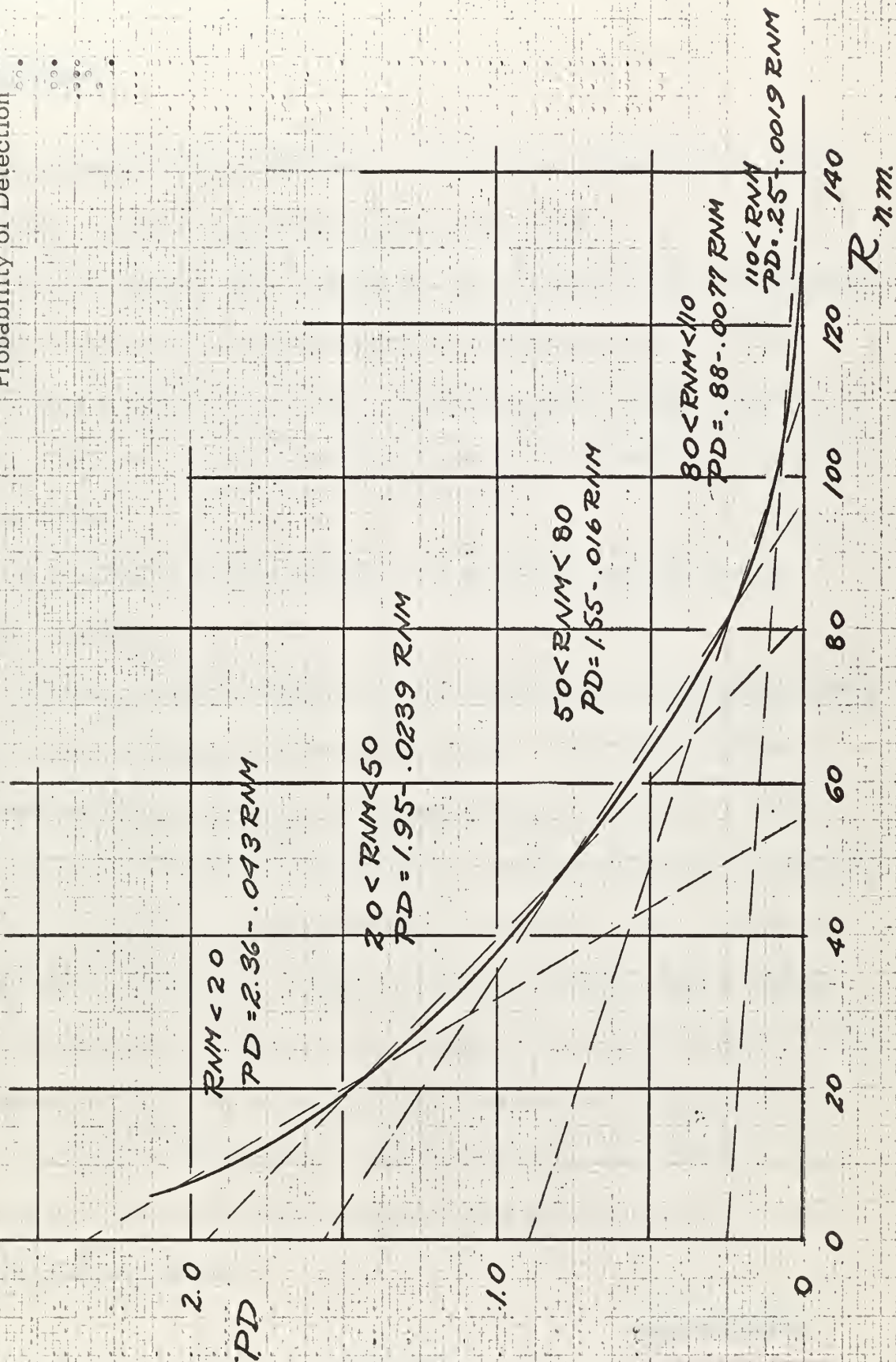
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Name		Address		Phone	
1. Mr. Zhang		2. Mr. Li		3. Mr. Wang	
4. Mr. Chen		5. Mr. Liu		6. Mr. Zhao	
7. Mr. Sun		8. Mr. Zhou		9. Mr. Wu	
10. Mr. Yang		11. Mr. Xie		12. Mr. Xu	
13. Mr. Hu		14. Mr. Gao		15. Mr. Ma	
16. Mr. Lin		17. Mr. He		18. Mr. Shi	
19. Mr. Zhang		20. Mr. Li		21. Mr. Wang	
22. Mr. Chen		23. Mr. Liu		24. Mr. Zhao	
25. Mr. Sun		26. Mr. Zhou		27. Mr. Wu	
28. Mr. Yang		29. Mr. Xie		30. Mr. Xu	
31. Mr. Hu		32. Mr. Gao		33. Mr. Ma	
34. Mr. Lin		35. Mr. He		36. Mr. Shi	
37. Mr. Zhang		38. Mr. Li		39. Mr. Wang	
40. Mr. Chen		41. Mr. Liu		42. Mr. Zhao	
43. Mr. Sun		44. Mr. Zhou		45. Mr. Wu	
46. Mr. Yang		47. Mr. Xie		48. Mr. Xu	
49. Mr. Hu		50. Mr. Gao		51. Mr. Ma	
52. Mr. Lin		53. Mr. He		54. Mr. Shi	
55. Mr. Zhang		56. Mr. Li		57. Mr. Wang	
58. Mr. Chen		59. Mr. Liu		60. Mr. Zhao	
61. Mr. Sun		62. Mr. Zhou		63. Mr. Wu	
64. Mr. Yang		65. Mr. Xie		66. Mr. Xu	
67. Mr. Hu		68. Mr. Gao		69. Mr. Ma	
70. Mr. Lin		71. Mr. He		72. Mr. Shi	
73. Mr. Zhang		74. Mr. Li		75. Mr. Wang	
76. Mr. Chen		77. Mr. Liu		78. Mr. Zhao	
79. Mr. Sun		80. Mr. Zhou		81. Mr. Wu	
82. Mr. Yang		83. Mr. Xie		84. Mr. Xu	
85. Mr. Hu		86. Mr. Gao		87. Mr. Ma	
88. Mr. Lin		89. Mr. He		90. Mr. Shi	
91. Mr. Zhang		92. Mr. Li		93. Mr. Wang	
94. Mr. Chen		95. Mr. Liu		96. Mr. Zhao	
97. Mr. Sun		98. Mr. Zhou		99. Mr. Wu	
100. Mr. Yang		101. Mr. Xie		102. Mr. Xu	
103. Mr. Hu		104. Mr. Gao		105. Mr. Ma	
106. Mr. Lin		107. Mr. He		108. Mr. Shi	
109. Mr. Zhang		110. Mr. Li		111. Mr. Wang	
112. Mr. Chen		113. Mr. Liu		114. Mr. Zhao	
115. Mr. Sun		116. Mr. Zhou		117. Mr. Wu	
118. Mr. Yang		119. Mr. Xie		120. Mr. Xu	
121. Mr. Hu		122. Mr. Gao		123. Mr. Ma	
124. Mr. Lin		125. Mr. He		126. Mr. Shi	
127. Mr. Zhang		128. Mr. Li		129. Mr. Wang	
130. Mr. Chen		131. Mr. Liu		132. Mr. Zhao	
133. Mr. Sun		134. Mr. Zhou		135. Mr. Wu	
136. Mr. Yang		137. Mr. Xie		138. Mr. Xu	
139. Mr. Hu		140. Mr. Gao		141. Mr. Ma	
142. Mr. Lin		143. Mr. He		144. Mr. Shi	
145. Mr. Zhang		146. Mr. Li		147. Mr. Wang	
148. Mr. Chen		149. Mr. Liu		150. Mr. Zhao	
151. Mr. Sun		152. Mr. Zhou		153. Mr. Wu	
154. Mr. Yang		155. Mr. Xie		156. Mr. Xu	
157. Mr. Hu		158. Mr. Gao		159. Mr. Ma	
160. Mr. Lin		161. Mr. He		162. Mr. Shi	
163. Mr. Zhang		164. Mr. Li		165. Mr. Wang	
166. Mr. Chen		167. Mr. Liu		168. Mr. Zhao	
169. Mr. Sun		170. Mr. Zhou		171. Mr. Wu	
172. Mr. Yang		173. Mr. Xie		174. Mr. Xu	
175. Mr. Hu		176. Mr. Gao		177. Mr. Ma	
178. Mr. Lin		179. Mr. He		180. Mr. Shi	
181. Mr. Zhang		182. Mr. Li		183. Mr. Wang	
184. Mr. Chen		185. Mr. Liu		186. Mr. Zhao	
187. Mr. Sun		188. Mr. Zhou		189. Mr. Wu	
190. Mr. Yang		191. Mr. Xie		192. Mr. Xu	
193. Mr. Hu		194. Mr. Gao		195. Mr. Ma	
196. Mr. Lin		197. Mr. He		198. Mr. Shi	
199. Mr. Zhang		200. Mr. Li		201. Mr. Wang	
202. Mr. Chen		203. Mr. Liu		204. Mr. Zhao	
205. Mr. Sun		206. Mr. Zhou		207. Mr. Wu	
208. Mr. Yang		209. Mr. Xie		210. Mr. Xu	
211. Mr. Hu		212. Mr. Gao		213. Mr. Ma	
214. Mr. Lin		215. Mr. He		216. Mr. Shi	
217. Mr. Zhang		218. Mr. Li		219. Mr. Wang	
220. Mr. Chen		221. Mr. Liu		222. Mr. Zhao	
223. Mr. Sun		224. Mr. Zhou		225. Mr. Wu	
226. Mr. Yang		227. Mr. Xie		228. Mr. Xu	
229. Mr. Hu		230. Mr. Gao		231. Mr. Ma	
232. Mr. Lin		233. Mr. He		234. Mr. Shi	
235. Mr. Zhang		236. Mr. Li		237. Mr. Wang	
238. Mr. Chen		239. Mr. Liu		240. Mr. Zhao	
241. Mr. Sun		242. Mr. Zhou		243. Mr. Wu	
244. Mr. Yang		245. Mr. Xie		246. Mr. Xu	
247. Mr. Hu		248. Mr. Gao		249. Mr. Ma	
250. Mr. Lin		251. Mr. He		252. Mr. Shi	
253. Mr. Zhang		254. Mr. Li		255. Mr. Wang	
256. Mr. Chen		257. Mr. Liu		258. Mr. Zhao	
259. Mr. Sun		260. Mr. Zhou		261. Mr. Wu	
262. Mr. Yang		263. Mr. Xie		264. Mr. Xu	
265. Mr. Hu		266. Mr. Gao		267. Mr. Ma	
268. Mr. Lin		269. Mr. He		270. Mr. Shi	
271. Mr. Zhang		272. Mr. Li		273. Mr. Wang	
274. Mr. Chen		275. Mr. Liu		276. Mr. Zhao	
277. Mr. Sun		278. Mr. Zhou		279. Mr. Wu	
280. Mr. Yang		281. Mr. Xie		282. Mr. Xu	
283. Mr. Hu		284. Mr. Gao		285. Mr. Ma	
286. Mr. Lin		287. Mr. He		288. Mr. Shi	
289. Mr. Zhang		290. Mr. Li		291. Mr. Wang	
292. Mr. Chen		293. Mr. Liu		294. Mr. Zhao	
295. Mr. Sun		296. Mr. Zhou		297. Mr. Wu	
298. Mr. Yang		299. Mr. Xie		300. Mr. Xu	
301. Mr. Hu		302. Mr. Gao		303. Mr. Ma	
304. Mr. Lin		305. Mr. He		306. Mr. Shi	
307. Mr. Zhang		308. Mr. Li		309. Mr. Wang	
310. Mr. Chen		311. Mr. Liu		312. Mr. Zhao	
313. Mr. Sun		314. Mr. Zhou		315. Mr. Wu	
316. Mr. Yang		317. Mr. Xie		318. Mr. Xu	
319. Mr. Hu		320. Mr. Gao		321. Mr. Ma	
322. Mr. Lin		323. Mr. He		324. Mr. Shi	
325. Mr. Zhang		326. Mr. Li		327. Mr. Wang	
328. Mr. Chen		329. Mr. Liu		330. Mr. Zhao	
331. Mr. Sun		332. Mr. Zhou		333. Mr. Wu	
334. Mr. Yang		335. Mr. Xie		336. Mr. Xu	
337. Mr. Hu		338. Mr. Gao		339. Mr. Ma	
340. Mr. Lin		341. Mr. He		342. Mr. Shi	
343. Mr. Zhang		344. Mr. Li		345. Mr. Wang	
346. Mr. Chen		347. Mr. Liu		348. Mr. Zhao	
349. Mr. Sun		350. Mr. Zhou		351. Mr. Wu	
352. Mr. Yang		353. Mr. Xie		354. Mr. Xu	
355. Mr. Hu		356. Mr. Gao		357. Mr. Ma	
358. Mr. Lin		359. Mr. He		360. Mr. Shi	
361. Mr. Zhang		362. Mr. Li		363. Mr. Wang	
364. Mr. Chen		365. Mr. Liu		366. Mr. Zhao	
367. Mr. Sun		368. Mr. Zhou		369. Mr. Wu	
370. Mr. Yang		371. Mr. Xie		372. Mr. Xu	
373. Mr. Hu		374. Mr. Gao		375. Mr. Ma	
376. Mr. Lin		377. Mr. He		378. Mr. Shi	
379. Mr. Zhang		380. Mr. Li		381. Mr. Wang	
382. Mr. Chen		383. Mr. Liu		384. Mr. Zhao	
385. Mr. Sun		386. Mr. Zhou		387. Mr. Wu	
388. Mr. Yang		389. Mr. Xie		390. Mr. Xu	
391. Mr. Hu		392.			

Figure 6

Normal Curve Adapted To Provide
Probability of Detection



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In the actual system this would be the status of the individual track in the TWS loop after being correlated and associated.

A quality counter, NQ, was devised for the program which incremented in steps of two for each received return to a maximum of ten. For each missed return it degenerated by one. When the quality counter reached zero the track was dropped and no smoothing was performed until the next received return.

The particulars of the smoothing and prediction section were as described earlier.

The primary quality indicator for the system was the three dimensional rms smoothed difference from the actual position. Since high relative velocities between the missile and the target are considered very likely in the active phase of the missile flight it is necessary that the missile be positioned accurately at the beginning of this period so that its maneuvers may be kept to a minimum. In order to assist in achieving this a desired rms smoothing error limitation of approximately one-half mile inside 50 miles was imposed. On the output curves points were plotted indicating these limits. For range constant lines of points at plus or minus one-half mile were plotted. For azimuth and elevation points were plotted as a function of range using the relation:

$$\Delta \theta = \frac{1}{2} \frac{V_r}{V_t} \frac{R}{R_0} \quad \Delta \phi = \frac{1}{2} \frac{V_r}{V_t} \frac{R}{R_0} \sin \theta$$

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$$\text{Angular error Maximum} = \text{ARCTAN} \frac{0.5}{\text{RNM.}}$$

If all the parameters were smoothed to the desired value the three dimensional rms error, CIRSMO, could be as high as 0.875n.m. Thus on the curves of CIRSMO a line of points having this value were plotted.

The program print out contained the run number, problem time, actual range, rms three dimensional actual error, CIRERR, rms three dimensional smoothed error, CIRSMO, a one or zero for detection or no detection, ND, and the status of the quality counter, NQ. When the quality counter was zero no contact was assumed and all nines were printed out.

To observe the results of the smoothing method the sub-routine CALL DRAW was used to plot the interceptor and target positions in the north-east, N-E, plane, looking down from above, and the north-down, N-D, plane, looking in from the east axis. The sub~~routine~~ was also used to plot the difference between the actual and smoothed values of range and the direction cosines, which were plotted as angular differences, and the values of the three dimensional rms smoothed error.

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6. Results of the Analysis of the Proposed System

Table II contains the important details of the problem profiles used in the analysis. The results of run 1A are shown in Table III and Figures 7 to 15. The results of runs 2A and 3A are shown in Appendix D.

Three basic profiles were considered. These were identified by the initial position and heading of the target with respect to the interceptor. For run 1 the target was positioned at 100 n.m. and was closing the interceptor. For run 2 the target was positioned at 10 n.m. and was moving away from the interceptor. In run 3 the target was positioned at approximately 60 n.m. at a 30 degree angle from the interceptor and was headed on a cross track with respect to it. The actual profiles flown by the target and the interceptor could be varied in a myriad of ways, however in reaching the conclusions that follow only those flight paths shown in Table II were used.

The results obtained for the system, as proposed by Hughes, indicated that the smoothed tracks were still quite noisy. The direction cosine smoothing results obtained by analyzing the figures of these values compared to the desired limits indicated that the direction cosines were being smoothed inside the limits rather well. Some degradation was noted in the cross track cases

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PHYSICS 435: QUANTUM MECHANICS
LECTURE 10: THE HARMONIC OSCILLATOR
PROFESSOR JOHN SMITH
WINTER 2024

The harmonic oscillator is a fundamental model in quantum mechanics. It describes a particle of mass m attached to a spring with force constant k . The potential energy is given by $V(x) = \frac{1}{2}kx^2$. The Schrödinger equation for the harmonic oscillator is

$$-\frac{\hbar^2}{2m} \frac{d^2 \psi}{dx^2} + \frac{1}{2}kx^2 \psi = E \psi$$

The energy levels of the harmonic oscillator are quantized and given by

$$E_n = \left(n + \frac{1}{2}\right) \hbar \omega$$

where $n = 0, 1, 2, \dots$ is the quantum number and $\omega = \sqrt{k/m}$ is the angular frequency. The wave functions for the harmonic oscillator are given by

$$\psi_n(x) = \frac{1}{\sqrt{2^n n!}} \left(\frac{m\omega}{\pi\hbar}\right)^{1/4} e^{-\frac{m\omega x^2}{2\hbar}} H_n\left(\sqrt{\frac{m\omega}{\hbar}} x\right)$$

where H_n are the Hermite polynomials. The probability density for finding the particle at position x is given by $|\psi_n(x)|^2$.

The harmonic oscillator is a special case of the more general anharmonic oscillator. In the anharmonic oscillator, the potential energy is given by $V(x) = \frac{1}{2}kx^2 + \frac{1}{3}bx^3 + \frac{1}{4}cx^4$. The energy levels of the anharmonic oscillator are not exactly quantized and the wave functions are more complicated.

The harmonic oscillator is also a special case of the more general quantum harmonic oscillator. In the quantum harmonic oscillator, the potential energy is given by $V(x) = \frac{1}{2}kx^2$ and the wave functions are given by $\psi_n(x) = \frac{1}{\sqrt{2^n n!}} \left(\frac{m\omega}{\pi\hbar}\right)^{1/4} e^{-\frac{m\omega x^2}{2\hbar}} H_n\left(\sqrt{\frac{m\omega}{\hbar}} x\right)$.

PHYSICS 435: QUANTUM MECHANICS

TABLE II

FLIGHT PROFILES USED IN ANALYSIS

TARGET

Run Number	INITIAL PARAMETERS				Final Altitude ^{ft}	TIME TO	
	Nnm	Enm	D ft (above S.L.)	Heading ^{deg}		Turn ^{sec}	Dive ^{sec}
1 A B C	100	-10	40,000	180	1000 40,000 40,000	150 None 150	150 None None
2 A B C	10	-10	40,000	360	1000 40,000 40,000	150 None 150	150 None None
3 A B C	50	-40	40,000	090	1000 40,000 40,000	150 None 150	150 None None

Note: Target maneuver capabilities are: Turn 6_g, Dive -3_g, and Pull Out 6_g.

INTERCEPTOR

Heading ^{deg}	Mach No	Altitude ^{ft}
350	0.7	37,000

SMOOTHING RESULTS

RUN 1A

T=TIME, R NM=ACTUAL RANGE, CIRERR=3DIMENSIONAL RMS ACTUAL ERROR,
CIRSMO=3 DIMENSIONAL RMS SMOOTHED ERROR, ND=1 DETECTION, ND=0 NO
DETECTION, NQ=QUALITY COUNTER, WHEN NQ=0 TARGET CONSIDERED LOST AND
ALL NINES ARE PRINTED.

T	R NM	CIRERR	CIRSMO	ND	NQ
.	100.5000	999.9999	999.9999	99	0
2.	99.4871	999.9999	999.9999	99	0
4.	98.4809	999.9999	999.9999	99	0
6.	97.4805	2.8089	2.8089	1	2
8.	96.4819	.3501	2.7924	0	1
10.	95.4829	999.9999	999.9999	99	0
12.	94.4808	999.9999	999.9999	99	0
14.	93.4664	999.9999	999.9999	99	0
16.	92.4470	999.9999	999.9999	99	0
18.	91.4370	999.9999	999.9999	99	0
20.	90.4195	999.9999	999.9999	99	0
22.	89.3964	999.9999	999.9999	99	0
24.	88.3717	999.9999	999.9999	99	0
26.	87.3507	999.9999	999.9999	99	0
28.	86.3438	2.1180	2.1180	1	2
30.	85.3354	1.6702	2.0969	0	1
32.	84.3289	999.9999	999.9999	99	0
34.	83.3276	3.9403	3.9403	1	2
36.	82.3209	2.5368	3.9162	0	1
38.	81.3087	.7825	2.4350	1	3
40.	80.2970	3.2225	2.3204	0	2
42.	79.2848	.9345	2.2242	0	1
44.	78.2667	999.9999	999.9999	99	0
46.	77.2543	2.7971	2.7971	1	2
48.	76.2567	2.4162	2.8147	0	1
50.	75.2688	999.9999	999.9999	99	0
52.	74.2774	999.9999	999.9999	99	0
54.	73.2785	999.9999	999.9999	99	0
56.	72.2763	.7391	.7391	1	2
58.	71.2801	3.5905	1.1076	1	4
60.	70.2918	2.9569	1.2629	0	3
62.	69.2966	1.8983	1.4499	0	2
64.	68.2990	2.9966	1.5692	1	4
66.	67.3133	.3755	.7502	1	6
68.	66.3347	3.4902	.7604	0	5
70.	65.3566	2.4328	.7920	0	4
72.	64.3877	2.9470	1.6471	1	6
74.	63.4255	4.4218	1.7263	0	5
76.	62.4593	4.4005	1.8257	0	4
78.	61.4952	.8885	1.9355	0	3
80.	60.5331	.8715	1.1710	1	5
82.	59.5727	3.2183	1.2012	0	4
84.	58.6241	6.4126	1.2271	0	3
86.	57.6929	1.9297	1.2447	0	2
88.	56.7703	1.5748	1.2605	0	1
90.	55.8405	2.2930	1.6465	1	3
92.	54.9099	1.0705	1.3791	0	2
94.	53.9813	4.2629	1.7212	0	1
96.	53.0444	999.9999	999.9999	99	0
98.	52.1038	2.9109	2.9109	1	2
100.	51.1811	2.3925	2.8871	0	1
102.	50.2683	1.2764	2.1161	1	3

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104.	49.3610	1.1716	2.1280	0	2
106.	48.4660	1.3300	2.1478	0	1
108.	47.5685	2.5272	.6311	1	3
110.	46.6623	1.6322	.7560	0	2
112.	45.7441	1.1995	.6104	1	4
114.	44.8111	2.4204	1.0049	1	5
116.	43.8711	2.3101	1.2709	1	8
118.	42.9232	2.0857	1.8194	1	10
120.	41.9624	1.6084	.9878	1	10
122.	40.9986	3.9664	1.5656	1	10
124.	40.0442	3.5859	.9143	1	10
126.	39.0998	1.0404	.8934	1	10
128.	38.1587	2.5277	.9466	0	9
130.	37.2168	4.0934	1.6227	1	10
132.	36.2832	3.0987	1.6066	0	9
134.	35.3557	3.7174	1.5809	0	8
136.	34.4268	1.4977	.3722	1	10
138.	33.4964	4.4075	.4850	0	9
140.	32.5567	1.4627	.6428	1	10
142.	31.6179	3.3400	1.8072	1	10
144.	30.6886	4.5131	1.1939	1	10
146.	29.7558	2.1345	1.4976	1	10
148.	28.8093	.9501	1.1917	1	10
150.	27.8563	1.1226	.8273	1	10
152.	26.8896	.7536	.6589	1	10
154.	25.9816	3.1620	.8572	0	9
156.	25.1572	5.4788	2.5853	1	10
158.	24.4380	4.1105	.9185	1	10
160.	23.8445	1.8564	.6228	1	10

162.	23.3933	3.3222	1.5404	1	10
164.	23.0952	5.0620	1.9082	1	10
166.	22.9552	.9599	1.7909	1	10
168.	22.9707	5.6214	2.4656	0	9
170.	23.1315	.3130	1.8425	1	10
172.	23.4222	1.0723	1.8749	1	10
174.	23.8221	1.1368	2.6427	0	9
176.	24.3080	4.4560	.2192	1	10
178.	24.8556	3.1212	1.1249	1	10
180.	25.4395	4.2445	2.2379	1	10
182.	26.0370	.5878	1.1206	1	10
184.	26.6251	2.1740	1.1881	0	9
186.	27.1849	2.3486	1.2085	1	10
188.	27.6986	2.4025	1.8340	1	10
190.	28.1555	.6367	2.0981	0	9
192.	28.6017	1.5670	1.8206	1	10
194.	29.0530	.7293	.8247	1	10
196.	29.5092	.3101	.3816	1	10
198.	29.9700	2.6407	.3614	0	9
200.	30.4338	.8438	.4553	1	10
202.	30.9019	2.0573	1.0997	1	10
204.	31.3732	1.6566	1.2539	1	10
206.	31.8487	2.2964	1.2489	0	9
208.	32.3273	3.7707	2.3333	1	10
210.	32.8086	3.1324	2.6509	1	10
212.	33.2933	1.0363	1.0451	1	10
214.	33.7606	1.5452	1.1826	1	10
216.	34.2715	1.3069	1.1601	0	9
218.	34.7654	.5480	1.1220	0	8
220.	35.2606	1.0041	.3621	1	10
222.	35.7582	2.1422	.7419	1	10
224.	36.2585	1.3269	1.0007	1	10

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TABLE III

226.	36.7614	2.1929	.6306	1	10
228.	37.2662	.4203	.5070	1	10
230.	37.7737	1.4021	.8871	1	10
232.	38.2827	2.2209	.8915	0	9
234.	38.7943	2.7467	1.6487	1	10
236.	39.3069	3.7272	.7716	1	10
238.	39.8210	.9506	.5839	1	10
240.	40.3378	.8783	.7262	1	10
242.	40.8568	2.7186	1.1963	1	10
244.	41.3762	6.0221	1.2214	0	9
246.	41.8975	1.1427	1.2499	0	8
248.	42.4203	3.5265	1.2827	0	7
250.	42.9449	.9221	1.0891	1	9
252.	43.4704	2.2873	.5461	1	10
254.	43.9969	1.0963	.2977	1	10
256.	44.5255	3.2416	1.3572	1	10
258.	45.0546	4.0951	1.1909	1	10
260.	45.5847	4.3770	1.2842	0	9
262.	46.1162	3.1601	1.8915	1	10
264.	46.6486	2.8110	2.2411	1	10
266.	47.1817	3.2857	.3059	1	10
268.	47.7164	5.9780	2.6170	1	10
270.	48.2523	1.3971	1.9555	1	10
272.	48.7889	3.5075	.7339	1	10
274.	49.3267	3.3489	.8322	0	9
276.	49.8658	.4459	.4249	1	10
278.	50.4053	1.0606	.6642	1	10
280.	50.9456	3.8362	2.0458	1	10
282.	51.4871	4.9476	1.1952	1	10
284.	52.0292	.8078	.5816	1	10
286.	52.5722	1.3545	.6306	0	9
288.	53.1158	1.9762	.9642	1	10
290.	53.6600	4.8418	1.0683	0	9
292.	54.2052	1.8616	1.1776	0	8
294.	54.7504	2.3180	1.2917	0	7
296.	55.2968	1.1498	.6087	1	9
298.	55.8440	2.4983	.6028	0	8
300.	56.3915	1.6145	.6383	0	7

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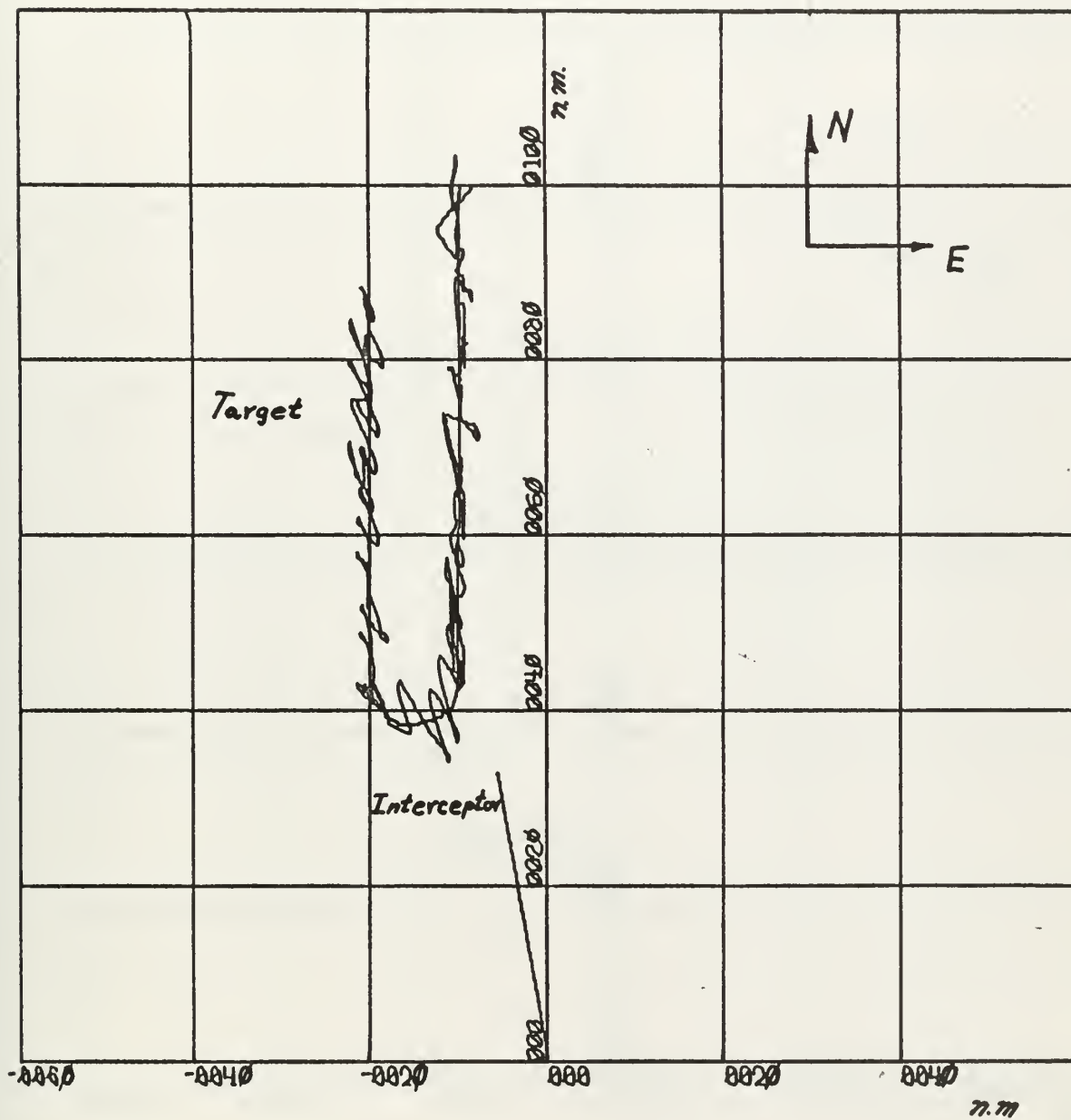
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FIGURE 7

X-SCALE = $2.00E+01$ UNITS/INCH.Y-SCALE = $2.00E+01$ UNITS/INCH.

CENTZ NE PLANE ACTUAL + NOISE ; RUN 1A

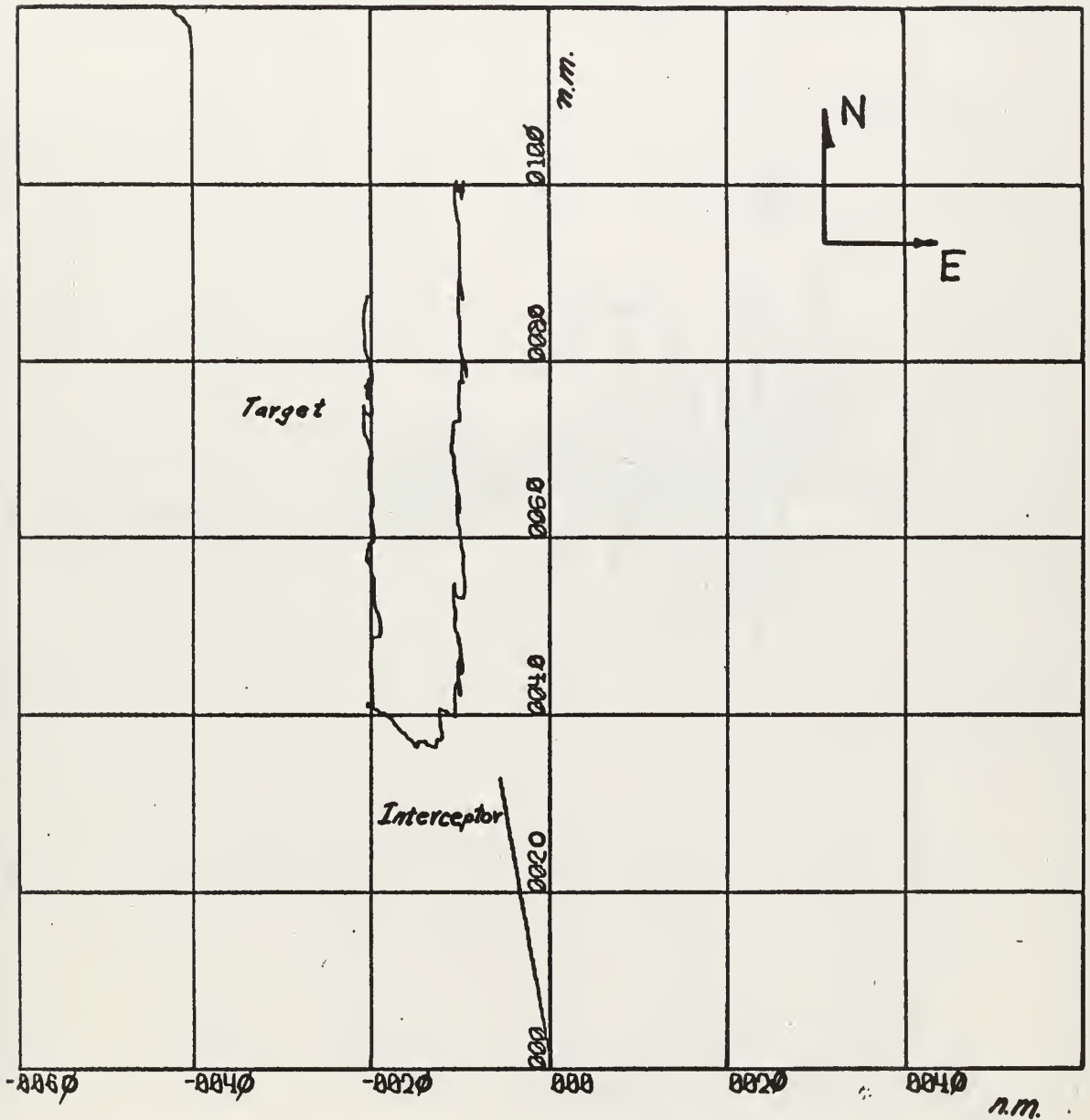
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1. The first part of the document discusses the importance of maintaining accurate records of all transactions.

Date		Description		Amount	
1/1/2023		Initial deposit		1000.00	
1/15/2023		Withdrawal for rent		500.00	
2/1/2023		Deposit from client		750.00	
2/15/2023		Withdrawal for utilities		250.00	
3/1/2023		Deposit from client		600.00	
3/15/2023		Withdrawal for salaries		800.00	
4/1/2023		Deposit from client		900.00	
4/15/2023		Withdrawal for office supplies		100.00	
5/1/2023		Deposit from client		1100.00	
5/15/2023		Withdrawal for taxes		300.00	
6/1/2023		Deposit from client		1200.00	
6/15/2023		Withdrawal for insurance		150.00	
7/1/2023		Deposit from client		1300.00	
7/15/2023		Withdrawal for maintenance		200.00	
8/1/2023		Deposit from client		1400.00	
8/15/2023		Withdrawal for interest		120.00	
9/1/2023		Deposit from client		1500.00	
9/15/2023		Withdrawal for depreciation		180.00	
10/1/2023		Deposit from client		1600.00	
10/15/2023		Withdrawal for legal fees		220.00	
11/1/2023		Deposit from client		1700.00	
11/15/2023		Withdrawal for advertising		240.00	
12/1/2023		Deposit from client		1800.00	
12/15/2023		Withdrawal for travel		260.00	
1/1/2024		Deposit from client		1900.00	
1/15/2024		Withdrawal for research		280.00	
2/1/2024		Deposit from client		2000.00	
2/15/2024		Withdrawal for consulting		300.00	
3/1/2024		Deposit from client		2100.00	
3/15/2024		Withdrawal for training		320.00	
4/1/2024		Deposit from client		2200.00	
4/15/2024		Withdrawal for equipment		340.00	
5/1/2024		Deposit from client		2300.00	
5/15/2024		Withdrawal for software		360.00	
6/1/2024		Deposit from client		2400.00	
6/15/2024		Withdrawal for hardware		380.00	
7/1/2024		Deposit from client		2500.00	
7/15/2024		Withdrawal for network		400.00	
8/1/2024		Deposit from client		2600.00	
8/15/2024		Withdrawal for security		420.00	
9/1/2024		Deposit from client		2700.00	
9/15/2024		Withdrawal for backup		440.00	
10/1/2024		Deposit from client		2800.00	
10/15/2024		Withdrawal for monitoring		460.00	
11/1/2024		Deposit from client		2900.00	
11/15/2024		Withdrawal for support		480.00	
12/1/2024		Deposit from client		3000.00	
12/15/2024		Withdrawal for documentation		500.00	

2. The second part of the document discusses the importance of maintaining accurate records of all transactions.

FIGURE 8



X-SCALE = 2.00E+01 UNITS/INCH

Y-SCALE = 2.00E+01 UNITS/INCH

GENTZ NE PLANE SMOOTHED POSITION RUN 1A

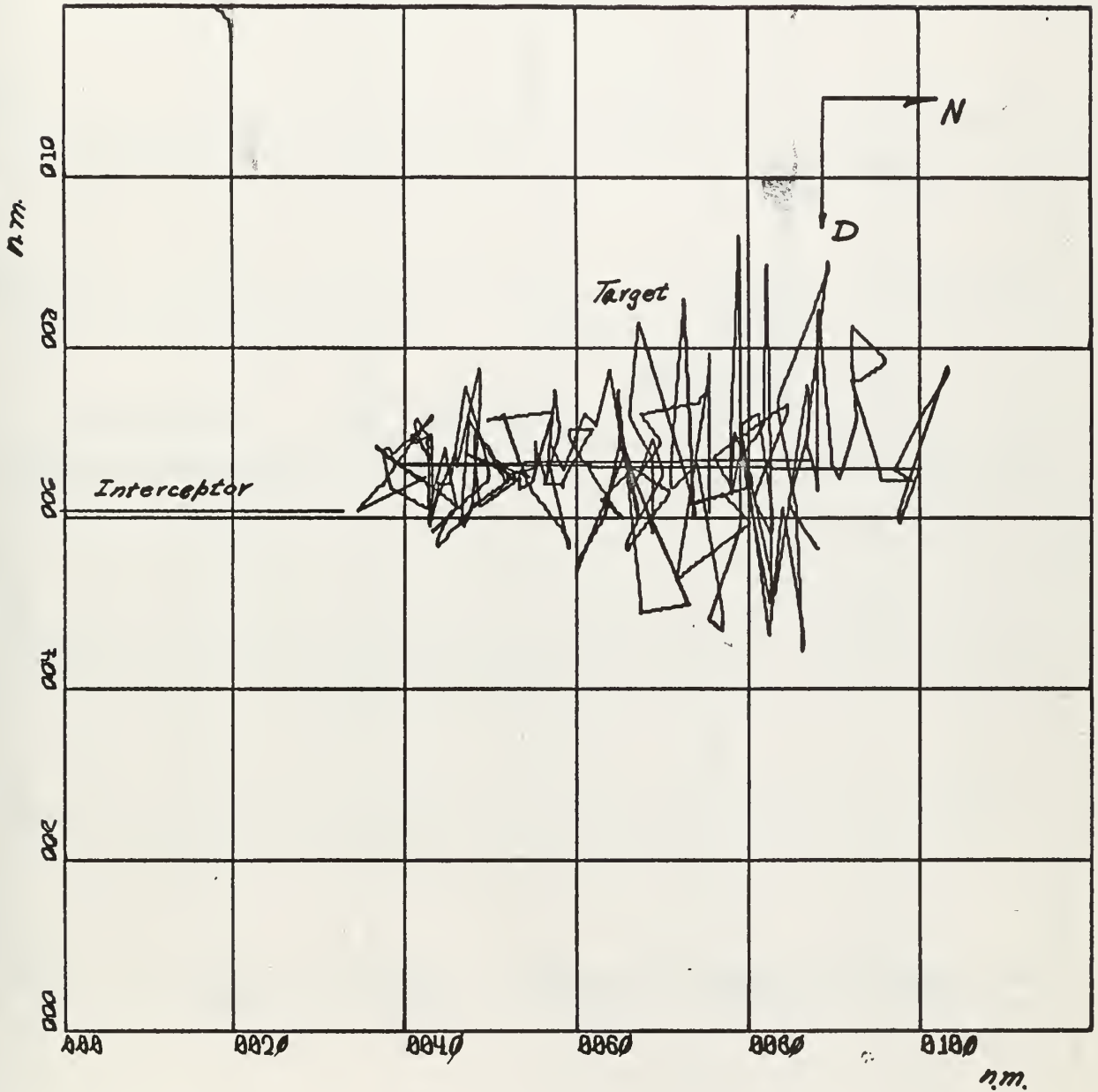
1. $x^2 + y^2 = 1$ (unit circle)
2. $x^2 + y^2 = 4$ (circle with radius 2)
3. $x^2 + y^2 = 9$ (circle with radius 3)
4. $x^2 + y^2 = 16$ (circle with radius 4)
5. $x^2 + y^2 = 25$ (circle with radius 5)
6. $x^2 + y^2 = 36$ (circle with radius 6)
7. $x^2 + y^2 = 49$ (circle with radius 7)
8. $x^2 + y^2 = 64$ (circle with radius 8)
9. $x^2 + y^2 = 81$ (circle with radius 9)
10. $x^2 + y^2 = 100$ (circle with radius 10)



1. $x^2 + y^2 = 1$ (unit circle)
2. $x^2 + y^2 = 4$ (circle with radius 2)
3. $x^2 + y^2 = 9$ (circle with radius 3)
4. $x^2 + y^2 = 16$ (circle with radius 4)
5. $x^2 + y^2 = 25$ (circle with radius 5)
6. $x^2 + y^2 = 36$ (circle with radius 6)
7. $x^2 + y^2 = 49$ (circle with radius 7)
8. $x^2 + y^2 = 64$ (circle with radius 8)
9. $x^2 + y^2 = 81$ (circle with radius 9)
10. $x^2 + y^2 = 100$ (circle with radius 10)

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FIGURE 9



X-SCALE = $2.00E+01$ UNITS/INCH

Y-SCALE = $2.00E+00$ UNITS/INCH

CENTZ NO PLANE ACTUAL + NOISE

RUN 1A

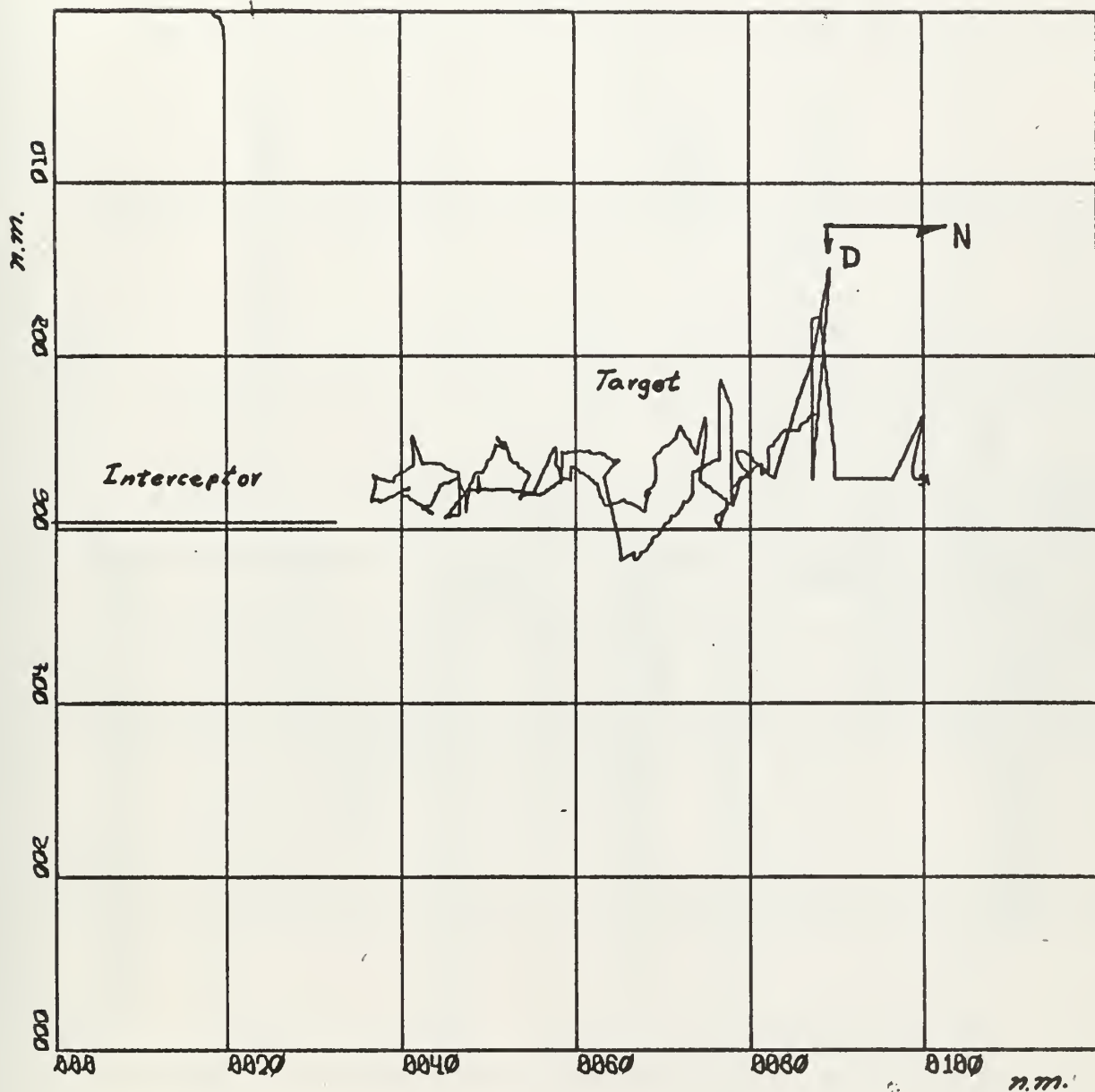
100-100000



100-100000

UNCLASSIFIED

FIGURE 10

X-SCALE = $2.00E+01$ UNITS/INCHY-SCALE = $2.00E+00$ UNITS/INCH

CENTZ ND: PLANE SMOOTHED POSITION RUN 1A

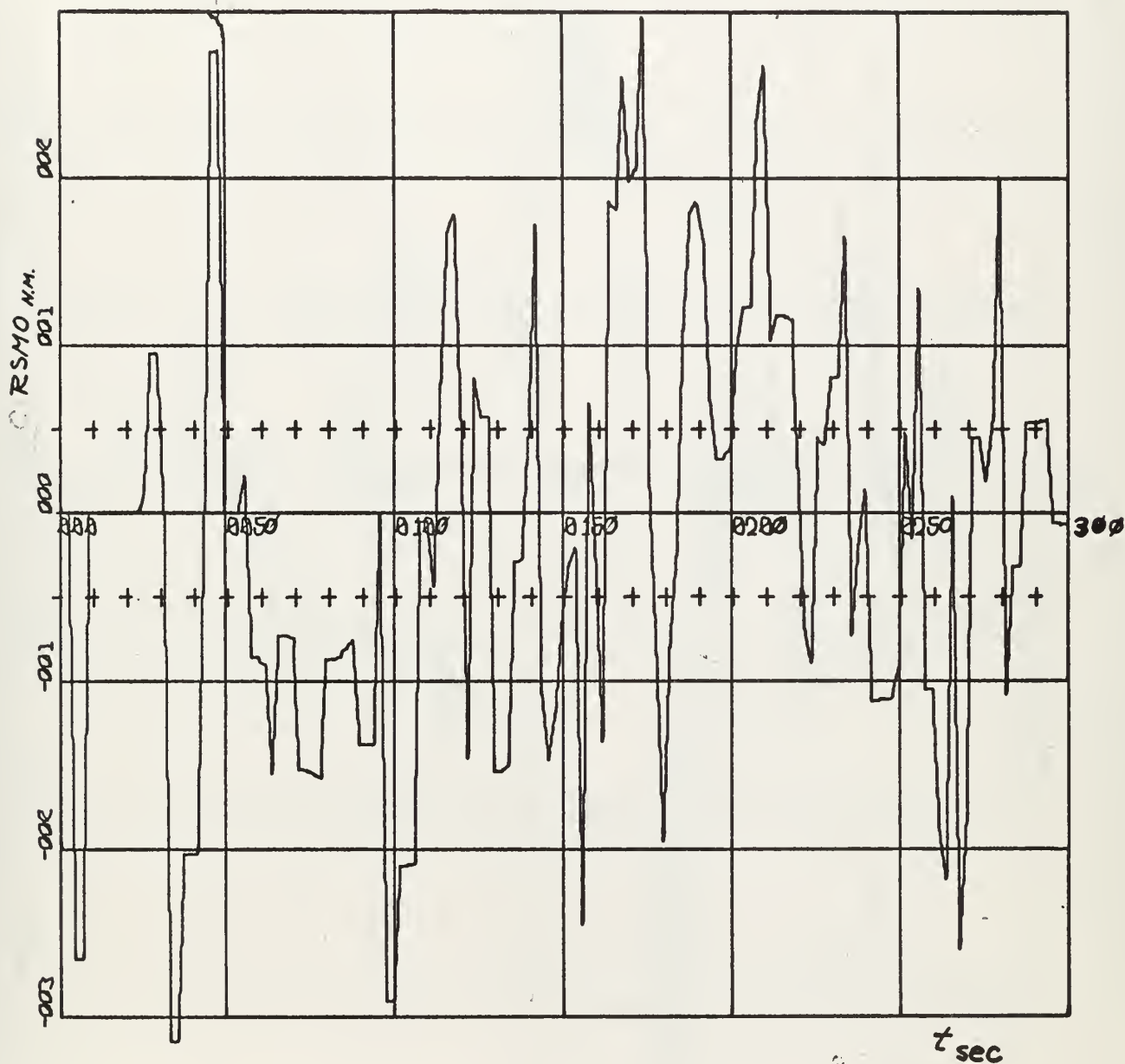
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SECRET

SECRET

UNCLASSIFIED

FIGURE 11

X-SCALE = $5.00\text{E}+01$ UNITS/INCHY-SCALE = $1.00\text{E}+00$ UNITS/INCH

GENTZ RANGE SMOOTHING RESULTS

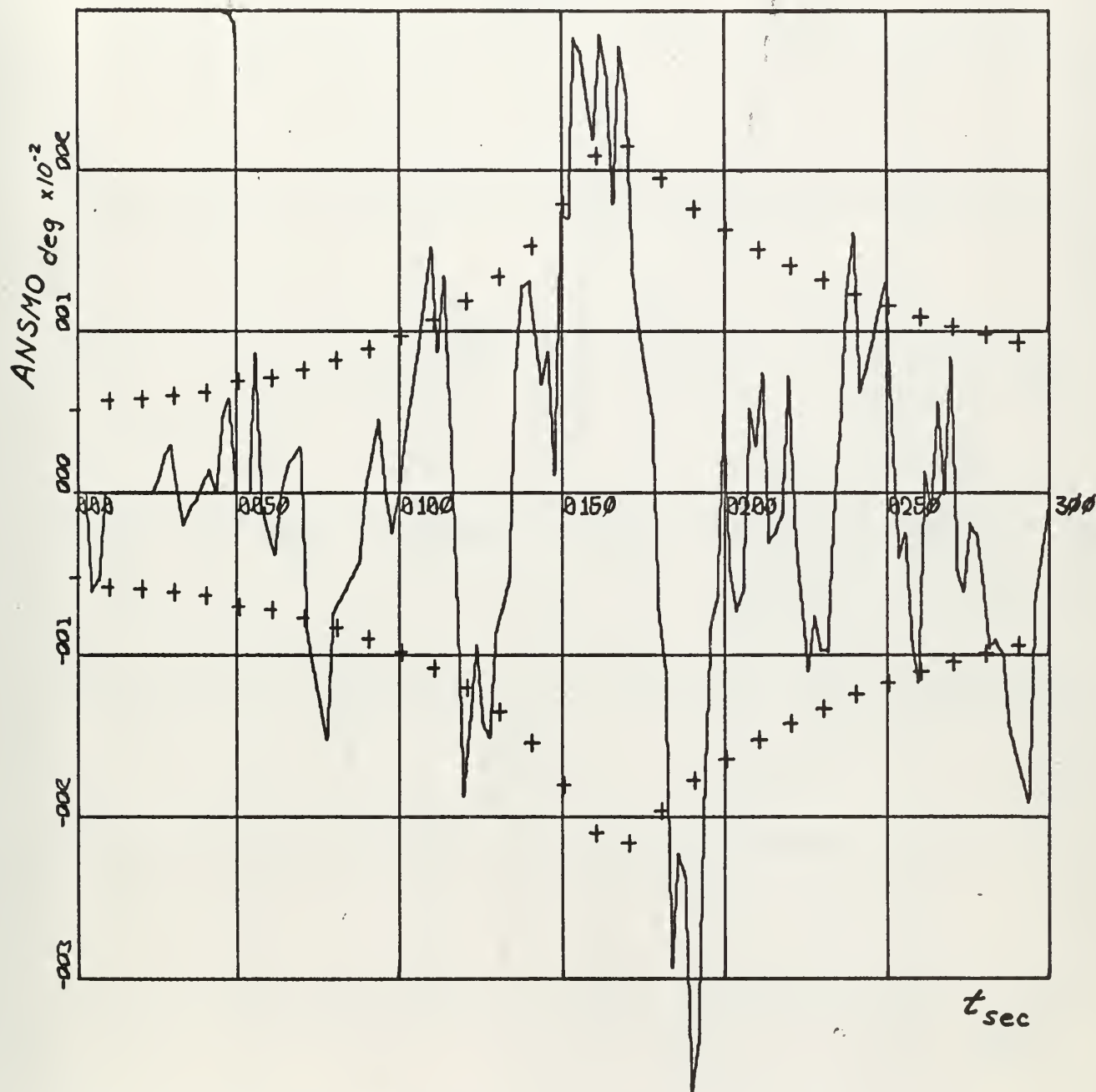
RUN 1A

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FIGURE 12



X-SCALE = 5.00E+01 UNITS/INCH

Y-SCALE = 1.00E-02 UNITS/INCH

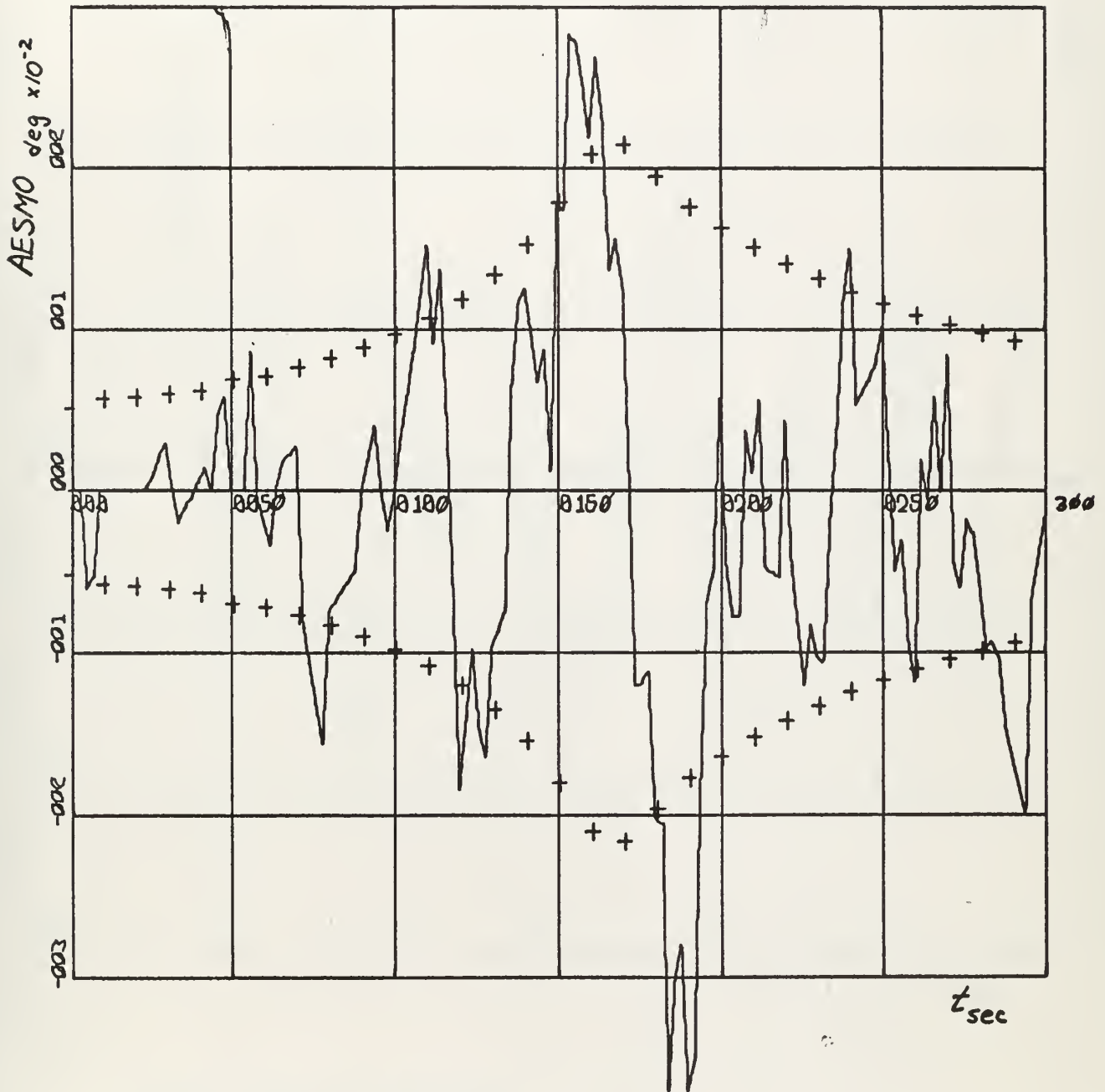
CENTZ NORTH SMOOTHING RESULTS

RUN 1A

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[illegible][illegible]

FIGURE 13



X-SCALE = 5.00E+01 UNITS/INCH

Y-SCALE = 1.00E-02 UNITS/INCH

GENTZ EAST SMOOTHING RESULTS

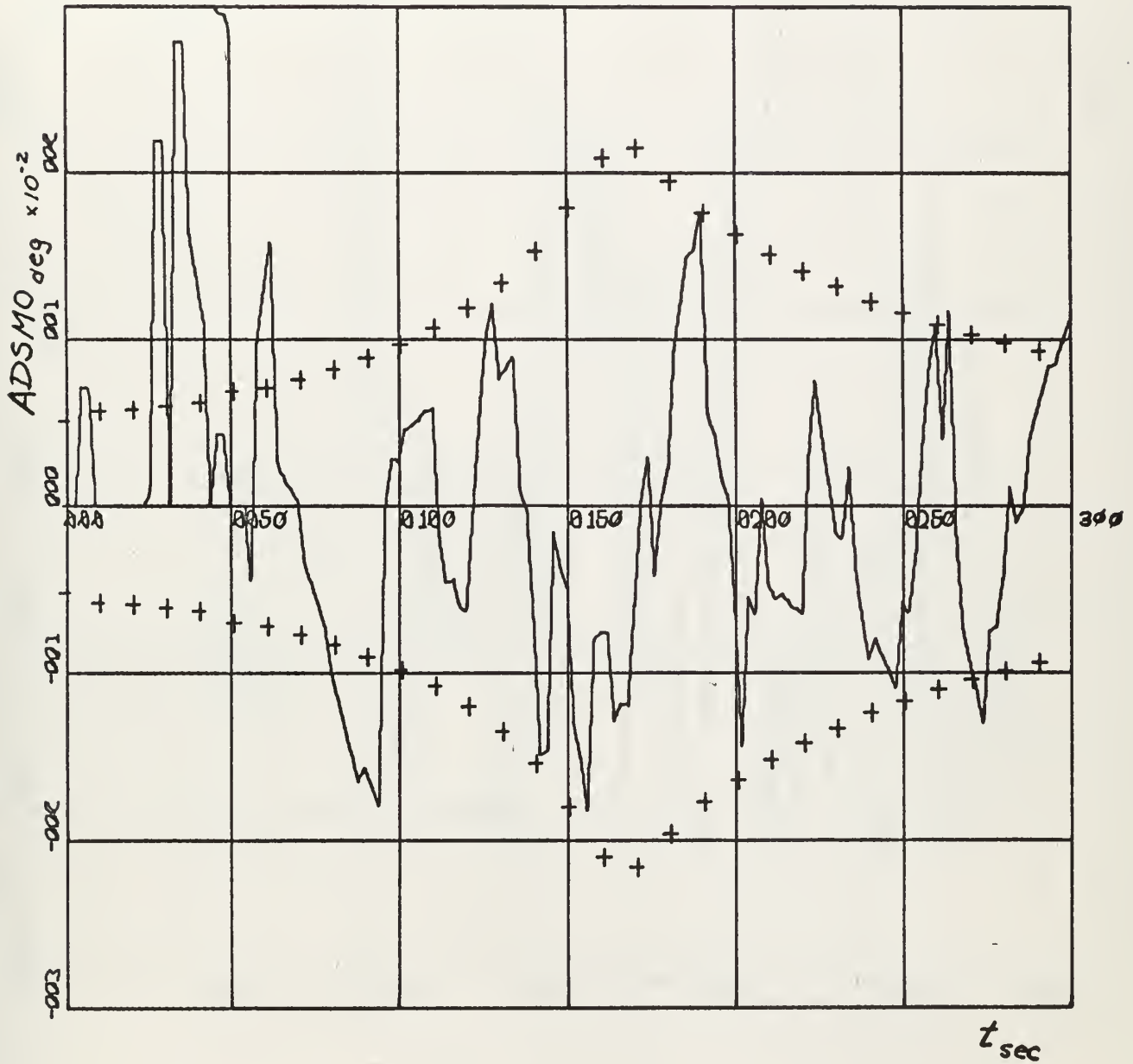
RUN 1A

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FIGURE 14



X-SCALE = 5.00E+01 UNITS/INCH

Y-SCALE = 1.00E-02 UNITS/INCH

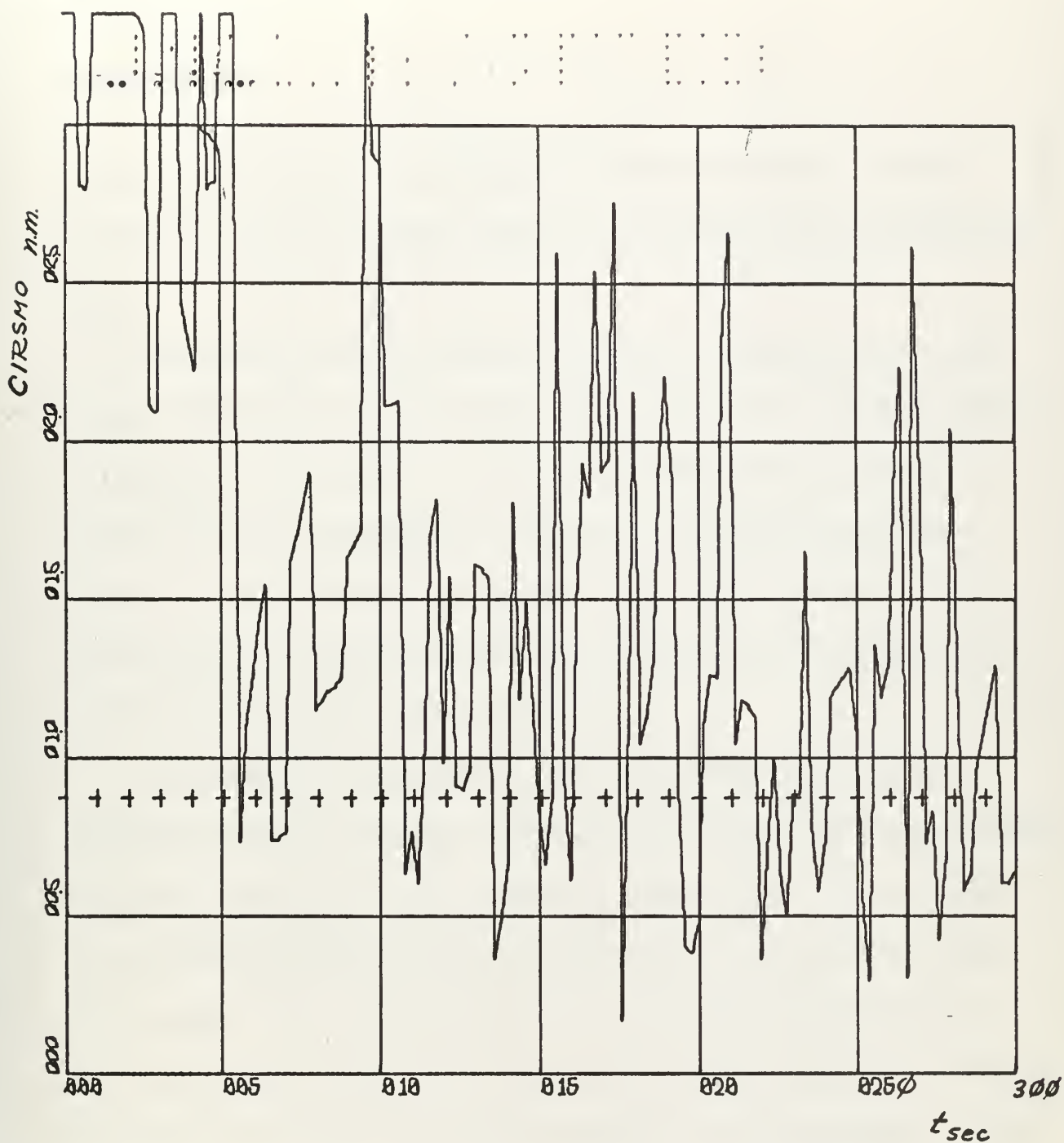
CENTZ DOWN SMOOTHING RESULTS

RUN 1A

031412241040

040702216180

FIGURE 15

X-SCALE = $5.00E+01$ UNITS/INCHY-SCALE = $5.00E-01$ UNITS/INCH

GENTZ 3D RMS SMOOTHING RESULTS

RUN 1A

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031712201040

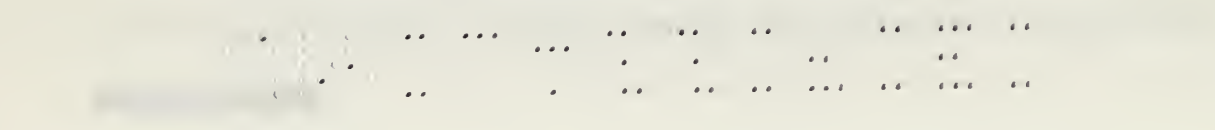
040702216160

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where the rates of change of the direction cosines were high. As was expected the range smoothing results were the prime cause of the smoothed error.

The system was able to smooth the tracks to within one and a half nautical miles inside 50 miles rather consistently, but it tended to respond rather strongly to the noise. It was noted, however, that this had the effect of causing no degradation in performance when the target began maneuvers. Also all the profiles yielded very similar smoothing results indicating that the smoothing constant values used were near optimum for the fixed constant, non-adaptive, system.

In an attempt to more closely define the optimum values of the smoothing constants a program which varied the constants for each smoothed parameter from 0.05 to 1.00 in steps of 0.05 was written. This program is named ALPHA CHECK and listed in Appendix C. The run profiles used were similar to those listed earlier, but, the run time was shortened to 100 seconds so that only the time that the target maneuvered was considered. The average mean square error for the complete run was computed for each smoothed quantity over the range of the values of its smoothing constant. An autocorrelation analysis was also performed to evaluate this noise distribution. The results are shown in Table IV. For these runs the



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TABLE IV

AUTOCORRELATION ANALYSIS RESULTS OF PROGRAM
ALPHA CHECK
(51 SAMPLES)

	Mean	Variance	Largest Value of Autocorrelation
RN 1 Target Acceleration Noise	-0.1735	0.6945	0.3947
RN 2 Target Heading Acceleration Noise	0.2439	1.1572	0.2662
RN 3 Target Pitch Acceleration Noise	-0.0986	.9622	0.1774
ATA Antenna Azimuth Noise	0.264	1.2022	-0.2493
EPSI Antenna Elevation Noise	-0.0765	0.8361	0.2544
R Radar Range Noise	0.1438	0.7524	0.2783
RDOT Radar Range Rate Noise	-0.0661	1.1695	0.2805
PD Radar Probability of Detection Noise	-0.0560	0.7587	0.3582

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1. The first part of the document is a list of the names of the people who were present at the meeting. The names are listed in alphabetical order.

Name		Address		Phone Number	
Mr. John Doe	123 Main St.	Anytown, CA 90210	(555) 123-4567	123-4567	123-4567
Mr. Jane Smith	456 Elm St.	Anytown, CA 90210	(555) 234-5678	234-5678	234-5678
Mr. Bob Johnson	789 Oak St.	Anytown, CA 90210	(555) 345-6789	345-6789	345-6789
Mr. Alice Brown	101 Pine St.	Anytown, CA 90210	(555) 456-7890	456-7890	456-7890
Mr. Charlie White	202 Pine St.	Anytown, CA 90210	(555) 567-8901	567-8901	567-8901
Mr. David Green	303 Pine St.	Anytown, CA 90210	(555) 678-9012	678-9012	678-9012
Mr. Emily Black	404 Pine St.	Anytown, CA 90210	(555) 789-0123	789-0123	789-0123
Mr. Frank Gray	505 Pine St.	Anytown, CA 90210	(555) 890-1234	890-1234	890-1234
Mr. Grace Hall	606 Pine St.	Anytown, CA 90210	(555) 901-2345	901-2345	901-2345
Mr. Henry King	707 Pine St.	Anytown, CA 90210	(555) 012-3456	012-3456	012-3456
Mr. Irene Lee	808 Pine St.	Anytown, CA 90210	(555) 123-4567	123-4567	123-4567
Mr. Jack Miller	909 Pine St.	Anytown, CA 90210	(555) 234-5678	234-5678	234-5678
Mr. Karen Wilson	1010 Pine St.	Anytown, CA 90210	(555) 345-6789	345-6789	345-6789
Mr. Larry Moore	1111 Pine St.	Anytown, CA 90210	(555) 456-7890	456-7890	456-7890
Mr. Mary Taylor	1212 Pine St.	Anytown, CA 90210	(555) 567-8901	567-8901	567-8901
Mr. Norman Anderson	1313 Pine St.	Anytown, CA 90210	(555) 678-9012	678-9012	678-9012
Mr. Olivia Thomas	1414 Pine St.	Anytown, CA 90210	(555) 789-0123	789-0123	789-0123
Mr. Paul Jackson	1515 Pine St.	Anytown, CA 90210	(555) 890-1234	890-1234	890-1234
Mr. Rachel Harris	1616 Pine St.	Anytown, CA 90210	(555) 901-2345	901-2345	901-2345
Mr. Steven Clark	1717 Pine St.	Anytown, CA 90210	(555) 012-3456	012-3456	012-3456
Mr. Tina Lewis	1818 Pine St.	Anytown, CA 90210	(555) 123-4567	123-4567	123-4567
Mr. Victor Wright	1919 Pine St.	Anytown, CA 90210	(555) 234-5678	234-5678	234-5678
Mr. Wendy Scott	2020 Pine St.	Anytown, CA 90210	(555) 345-6789	345-6789	345-6789
Mr. Xavier Adams	2121 Pine St.	Anytown, CA 90210	(555) 456-7890	456-7890	456-7890
Mr. Yolanda Baker	2222 Pine St.	Anytown, CA 90210	(555) 567-8901	567-8901	567-8901
Mr. Zachary Evans	2323 Pine St.	Anytown, CA 90210	(555) 678-9012	678-9012	678-9012
Mr. Adam Foster	2424 Pine St.	Anytown, CA 90210	(555) 789-0123	789-0123	789-0123
Mr. Brenda Gibson	2525 Pine St.	Anytown, CA 90210	(555) 890-1234	890-1234	890-1234
Mr. Charles Hill	2626 Pine St.	Anytown, CA 90210	(555) 901-2345	901-2345	901-2345
Mr. Diana King	2727 Pine St.	Anytown, CA 90210	(555) 012-3456	012-3456	012-3456
Mr. Edward Lee	2828 Pine St.	Anytown, CA 90210	(555) 123-4567	123-4567	123-4567
Mr. Fiona Miller	2929 Pine St.	Anytown, CA 90210	(555) 234-5678	234-5678	234-5678
Mr. George Wilson	3030 Pine St.	Anytown, CA 90210	(555) 345-6789	345-6789	345-6789
Mr. Hannah Moore	3131 Pine St.	Anytown, CA 90210	(555) 456-7890	456-7890	456-7890
Mr. Ian Taylor	3232 Pine St.	Anytown, CA 90210	(555) 567-8901	567-8901	567-8901
Mr. Julia Anderson	3333 Pine St.	Anytown, CA 90210	(555) 678-9012	678-9012	678-9012
Mr. Keith Thomas	3434 Pine St.	Anytown, CA 90210	(555) 789-0123	789-0123	789-0123
Mr. Laura Jackson	3535 Pine St.	Anytown, CA 90210	(555) 890-1234	890-1234	890-1234
Mr. Mark Harris	3636 Pine St.	Anytown, CA 90210	(555) 901-2345	901-2345	901-2345
Mr. Nancy Clark	3737 Pine St.	Anytown, CA 90210	(555) 012-3456	012-3456	012-3456
Mr. Oscar Lewis	3838 Pine St.	Anytown, CA 90210	(555) 123-4567	123-4567	123-4567
Mr. Patricia Wright	3939 Pine St.	Anytown, CA 90210	(555) 234-5678	234-5678	234-5678
Mr. Quincy Scott	4040 Pine St.	Anytown, CA 90210	(555) 345-6789	345-6789	345-6789
Mr. Rebecca Adams	4141 Pine St.	Anytown, CA 90210	(555) 456-7890	456-7890	456-7890
Mr. Samuel Baker	4242 Pine St.	Anytown, CA 90210	(555) 567-8901	567-8901	567-8901
Mr. Victoria Evans	4343 Pine St.	Anytown, CA 90210	(555) 678-9012	678-9012	678-9012
Mr. William Foster	4444 Pine St.	Anytown, CA 90210	(555) 789-0123	789-0123	789-0123
Mr. Xavier Gibson	4545 Pine St.	Anytown, CA 90210	(555) 890-1234	890-1234	890-1234
Mr. Yvonne Hill	4646 Pine St.	Anytown, CA 90210	(555) 901-2345	901-2345	901-2345
Mr. Zachary King	4747 Pine St.	Anytown, CA 90210	(555) 012-3456	012-3456	012-3456
Mr. Adam Lee	4848 Pine St.	Anytown, CA 90210	(555) 123-4567	123-4567	123-4567
Mr. Brenda Miller	4949 Pine St.	Anytown, CA 90210	(555) 234-5678	234-5678	234-5678
Mr. Charles Wilson	5050 Pine St.	Anytown, CA 90210	(555) 345-6789	345-6789	345-6789
Mr. Diana Moore	5151 Pine St.	Anytown, CA 90210	(555) 456-7890	456-7890	456-7890
Mr. Edward Taylor	5252 Pine St.	Anytown, CA 90210	(555) 567-8901	567-8901	567-8901
Mr. Fiona Anderson	5353 Pine St.	Anytown, CA 90210	(555) 678-9012	678-9012	678-9012
Mr. George Thomas	5454 Pine St.	Anytown, CA 90210	(555) 789-0123	789-0123	789-0123
Mr. Hannah Jackson	5555 Pine St.	Anytown, CA 90210	(555) 890-1234	890-1234	890-1234
Mr. Ian Harris	5656 Pine St.	Anytown, CA 90210	(555) 901-2345	901-2345	901-2345
Mr. Julia Clark	5757 Pine St.	Anytown, CA 90210	(555) 012-3456	012-3456	012-3456
Mr. Keith Lewis	5858 Pine St.	Anytown, CA 90210	(555) 123-4567	123-4567	123-4567
Mr. Laura Wright	5959 Pine St.	Anytown, CA 90210	(555) 234-5678	234-5678	234-5678
Mr. Mark Scott	6060 Pine St.	Anytown, CA 90210	(555) 345-6789	345-6789	345-6789
Mr. Nancy Adams	6161 Pine St.	Anytown, CA 90210	(555) 456-7890	456-7890	456-7890
Mr. Oscar Baker	6262 Pine St.	Anytown, CA 90210	(555) 567-8901	567-8901	567-8901
Mr. Patricia Evans	6363 Pine St.	Anytown, CA 90210	(555) 678-9012	678-9012	678-9012
Mr. Quincy Foster	6464 Pine St.	Anytown, CA 90210	(555) 789-0123	789-0123	789-0123
Mr. Rebecca Gibson	6565 Pine St.	Anytown, CA 90210	(555) 890-1234	890-1234	890-1234
Mr. Samuel Hill	6666 Pine St.	Anytown, CA 90210	(555) 901-2345	901-2345	901-2345
Mr. Victoria King	6767 Pine St.	Anytown, CA 90210	(555) 012-3456	012-3456	012-3456
Mr. William Lee	6868 Pine St.	Anytown, CA 90210	(555) 123-4567	123-4567	123-4567
Mr. Yvonne Miller	6969 Pine St.	Anytown, CA 90210	(555) 234-5678	234-5678	234-5678
Mr. Zachary Wilson	7070 Pine St.	Anytown, CA 90210	(555) 345-6789	345-6789	345-6789
Mr. Adam Moore	7171 Pine St.	Anytown, CA 90210	(555) 456-7890	456-7890	456-7890
Mr. Brenda Taylor	7272 Pine St.	Anytown, CA 90210	(555) 567-8901	567-8901	567-8901
Mr. Charles Anderson	7373 Pine St.	Anytown, CA 90210	(555) 678-9012	678-9012	678-9012
Mr. Diana Thomas	7474 Pine St.	Anytown, CA 90210	(555) 789-0123	789-0123	789-0123
Mr. Edward Jackson	7575 Pine St.	Anytown, CA 90210	(555) 890-1234	890-1234	890-1234
Mr. Fiona Harris	7676 Pine St.	Anytown, CA 90210	(555) 901-2345	901-2345	901-2345
Mr. George Clark	7777 Pine St.	Anytown, CA 90210	(555) 012-3456	012-3456	012-3456
Mr. Hannah Lewis	7878 Pine St.	Anytown, CA 90210	(555) 123-4567	123-4567	123-4567
Mr. Ian Wright	7979 Pine St.	Anytown, CA 90210	(555) 234-5678	234-5678	234-5678
Mr. Julia Scott	8080 Pine St.	Anytown, CA 90210	(555) 345-6789	345-6789	345-6789
Mr. Keith Adams	8181 Pine St.	Anytown, CA 90210	(555) 456-7890	456-7890	456-7890
Mr. Laura Baker	8282 Pine St.	Anytown, CA 90210	(555) 567-8901	567-8901	567-8901
Mr. Mark Evans	8383 Pine St.	Anytown, CA 90210	(555) 678-9012	678-9012	678-9012
Mr. Nancy Foster	8484 Pine St.	Anytown, CA 90210	(555) 789-0123	789-0123	789-0123
Mr. Oscar Gibson	8585 Pine St.	Anytown, CA 90210	(555) 890-1234	890-1234	890-1234
Mr. Patricia Hill	8686 Pine St.	Anytown, CA 90210	(555) 901-2345	901-2345	901-2345
Mr. Quincy King	8787 Pine St.	Anytown, CA 90210	(555) 012-3456	012-3456	012-3456
Mr. Rebecca Lee	8888 Pine St.	Anytown, CA 90210	(555) 123-4567	123-4567	123-4567
Mr. Samuel Miller	8989 Pine St.	Anytown, CA 90210	(555) 234-5678	234-5678	234-5678
Mr. Victoria Wilson	9090 Pine St.	Anytown, CA 90210	(555) 345-6789	345-6789	345-6789
Mr. William Moore	9191 Pine St.	Anytown, CA 90210	(555) 456-7890	456-7890	456-7890
Mr. Yvonne Taylor	9292 Pine St.	Anytown, CA 90210	(555) 567-8901	567-8901	567-8901
Mr. Zachary Anderson	9393 Pine St.	Anytown, CA 90210	(555) 678-9012	678-9012	678-9012
Mr. Adam Thomas	9494 Pine St.	Anytown, CA 90210	(555) 789-0123	789-0123	789-0123
Mr. Brenda Jackson	9595 Pine St.	Anytown, CA 90210	(555) 890-1234	890-1234	890-1234
Mr. Charles Harris	9696 Pine St.	Anytown, CA 90210	(555) 901-2345	901-2345	901-2345
Mr. Diana Clark	9797 Pine St.	Anytown, CA 90210	(555) 012-3456	012-3456	012-3456
Mr. Edward Lewis	9898 Pine St.	Anytown, CA 90210	(555) 123-4567	123-4567	123-4567
Mr. Fiona Wright	9999 Pine St.	Anytown, CA 90210	(555) 234-5678	234-5678	234-5678
Mr. George Scott	10000 Pine St.	Anytown, CA 90210	(555) 345-6789	345-6789	345-6789

2. The second part of the document is a list of the names of the people who were present at the meeting. The names are listed in alphabetical order.

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the probability of detection was one. This did not effect the results since no smoothing would have been performed when a contact was missed. The output would have been affected in an indeterminable way, however, by these predicted values.

The results of these runs are shown in Table V. It was apparent from these results that there was considerable interplay between all the variables. Some rationale could be seen in this interaction, but it appeared nonlinear, since any change in the target's profile varied all the points of the optimum values for the smoothing constants. It was noted further that the knuckle in the curves at the optimum point was quite sharp indicating that system performance could be seriously affected when improper values of the smoothing constants were used.

Due to the variations which were found in the optimum values of the smoothing constants for the chosen profiles it was not believed to be necessary to vary the parameters more widely since it was apparent from these runs that the system was very sensitive to changes in the profiles or the values of the system noise.

The question must then be asked as to whether the requirements established for the analysis were too strict. In this regard specifically

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TABLE V

OPTIMUM SMOOTHING CONSTANT VALUES
FOR
EACH TEST RUN

Run	Range	Direction Cosines		
		North	East	Down
1 A	0.1	0.25	0.25	0.35
1 B	0.05	0.25	0.25	0.05
1 C	0.15	0.35	0.35	0.05
2 A	0.25	0.90	0.85	0.65
2 B	0.05	0.65	0.55	0.10
2 C	0.35	0.95	0.95	0.40
3 A	0.50	0.60	0.65	0.55
3 B	0.45	0.70	0.55	0.05
3 C	0.55	0.75	0.80	0.05

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the standard deviation of range noise and the 0.5 mile value chosen for the desired smoothing error become suspect since they were somewhat arbitrarily chosen. In rebuttal it is strongly felt, in the light of the high overall performance required of the entire system, its cost, and purpose, that the use of this relatively uncontrollable method of smoothing could be disastrous. Since the output of the smoothing section has considerable control over the performance of the system, specifically the accurate positioning of the missile, it is believed that a more adaptive system is desirable. It is further felt that a programmed logic system which would provide for varying the values of the constants would not be warranted since more sophisticated, and proven adaptive systems are available. Possible choices for such a method could be either the Least Squares, or Kalman filter methods.

In short it must be concluded that the α , β , γ Tracker system does not have the response or versatility required for a high performance air to air intercept problem.

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APPENDIX A

TABLE OF SYMBOLS USED IN COMPUTER PROGRAMS

NOTE: If a symbol is used only in the ALPHA CHECK program it is so noted in parenthesis.

ADEV: Absolute value of deviation obtained from RNDEV.
This is used in the probability of detection computations.

ADSMO: Down, east, and north direction cosine differences

AESMO: from actual, and converted to radians.

ANSMO:

AD: (ALPHA CHECK) Values of alphas for down, east, and

AE: north direction cosines, and for range, used for determining

AN: the optimum values.

AR:

AERRM: Negative and positive desired limits on ADSMO, AESMO,

AERRP: and ANSMO, a function of actual range.

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MEMORANDUM

TO : THE PRESIDENT

FROM : THE SECRETARY OF DEFENSE

SUBJECT: [REDACTED]

1. [REDACTED]

2. [REDACTED]

3. [REDACTED]

4. [REDACTED]

5. [REDACTED]

6. [REDACTED]

7. [REDACTED]

8. [REDACTED]

9. [REDACTED]

10. [REDACTED]

11. [REDACTED]

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ALPHAD: Position smoothing constants for down, east and north

ALPHAE: direction cosines, and for range.

ALPHAN:

ALPHAR:

ANOISE: (ALPHA CHECK) Relative amount of radar parameter noise
used in problem.

AT: Target heading and turn rate used in computation of target's

ATDOT: position.

ATA: Antenna's actual and noisy azimuth angle measured positive

ATAE: , clockwise, in radians and degrees.

ATAD:

ATADE:

BETAD: Rate smoothing constants for down, east, and north

BETAE: direction cosines.

BETAN:

BT: Target's pitch angle and pitch angle rate used in computation

BTDOT: of target's position.

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CIRERR: Three dimensional RMS actual and smoothed error difference
CIRSMO: from actual target position.

DEV: Random deviation obtained from random number generator.

DT: Target position computation step size.

DIRN: North direction cosine actual, noisy, smoothed and
DIRNE: predicted.

DIRNS:

DIRNP:

DIRE: East direction cosine actual, noisy, smoothed and
DIREE: predicted.

DIRES:

DIREP:

DIRD: Down direction cosine actual, noisy, smoothed and
DIRDE: predicted.

DIRDS:

DIRDP:

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DIRND: North direction cosine, rate and acceleration.

DIRNDD:

DIRED: East direction cosine, rate and acceleration.

DIREDD:

DIRDD: Down direction cosine, rate and acceleration.

DIRDD:

DDSMO: (ALPHA CHECK) Down east and north direction cosine

DESMO: smoothing differences from actual.

DNSMO:

DELTAT: Target deceleration time to final velocity at -1.75 g.

DIVE: Target maximum dive angle, radians, corresponds to 60 deg.

EPSID: Antenna actual and noisy elevation angle measured positive

EPSIDE: downward, in radians and degrees.

EPSI:

EPSIE:

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NALPH: (ALPHA CHECK) Number of values of smoothing constants used in finding optimum value.

ND: A zero or one depending on whether detection was missed or not.

NERMAX: Number of points plotted indicating the desired limits on the smoothed errors.

NGRAF1:* Setting NGRAFS to zero supresses various portions of the

NGRAF2:* graph output.

NGRAF3:*

NOISE:* Number of times RNDEV is stepped prior to problem start to allow a different sequence of random numbers to be called.

NPRINT: Number which separates pages of print out.

NQ: Quality counter.

NQC: Counter which reinitializes the initial conditions after the quality counter goes to zero.

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NUMPTS: Number of curve points plotted.

NUNIF: Counter in random number generator.

OM:* Interceptor Mach number.

PD: Target detection probability for each frame time, a function of the actual range.

PI: 3.14159265.

POVERD: Target pushover rate, rad/sec.

POUTD: Target pull out rate, rad/sec.

PSIO: Interceptor heading in radians and degrees.

PSIOD:*

PSIT: Target heading.

PSITD:* Target initial heading, deg. and rad. Note a zero not an

PSITO: alphabetic o on target's initial positions.

Q: Number of frame times since last radar return of range rate.

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R: Actual and noisy range to target, ft and n.m.

RE:

RNM:

RNME:

RERRM: Negative and positive desired limits on range, a

RERRP: constant .5 n.m.

RDOT: Actual and noisy range rate of target with respect to

RDOTE: interceptor, positive opening, ft/sec.

RDOTM: Range rate actual, noisy, predicted, and smoothed,

RDOTME: n.m./sec.

RDOTMP:

RDOTMS:

RDDOTE: Target noisy acceleration, n.m./sec².

RN1: Random accelerations of target for velocity, heading,

RN2: and pitch.

RN3:

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RNMP: Predicted and smoothed range to target, n.m.

RNMS:

RSMO: Smoothed range error from actual, n.m.

T: Time since problem start.

TA: Total target iteration time since problem start.

TC: Iteration time which determines time for plotting
desired limit points.

TD:* Time to target dive.

TM:* Target Mach number.

TS: Check time against iteration time to enter main program
from target iteration.

TT:* Time to target turn.

VO: Interceptor velocity, ft/sec.

VT: Target velocity and acceleration, ft/sec. and ft/sec².

VTDOT:

VTF: Final target velocity, a function of the target's final
altitude.

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X1: Points which mark initial target location on the smoothed
X2: plot.

XO: Interceptor position along the north axis, ft. and n.m.

XONM:

XTERR: Difference between target's noisy and smoothed position,
n.m.

XTO:* Target position along north axis, initial, actual, and noisy

XT: in feet, and initial, noisy, and smoothed position, n.m.

XTE:

XTONM:

XTNME:

XTNMS:

XTSMO: Target's difference between actual and smoothed x position.

Y1: Similar to X1 and X2.

Y2:

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[illegible]

YTERR: Similar to XTERR.

YTO:* Target's position along the east axis, similar to X positions.

YT:

YTE:

YTONM:

YTNME:

YTNMS:

YTSMO: Target's difference between actual Y position and smoothed Y position.

Z1: Similar to X1 and X2.

Z2:

ZETA: Target's deflection angle from the horizontal, measured positive downward from the Interceptor, rad.

ZO:* Interceptor's altitude, ft. and n.m.

ZONM:

ZTERR: Similar to XTERR.

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ZTO:* Target's altitude similar to X positions.

ZT:

ZTE:

ZTNM:

ZTNME:

ZTNMS:

ZTSMO: Target's difference between actual Z position and smoothed
Z position.

ZTF:* Final target altitude, ft.

ZTPO: Target pull out altitude, ft.

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APPENDIX B

COMPUTER PROGRAM DETAILS

A. Purpose: The program is designed to generate three dimensional target-interceptor geometries for use in analyzing optimum smoothing schemes.

B. Limitations: The interceptor starts at the coordinate axis origin and may have any northerly heading. The target may be placed anywhere in the northern semi-circle with any initial heading. The positive axis directions are: X, north, Y, east, and Z, down, measured from the interceptor's altitude. The problem will stop anytime the target flies out of a 65 deg. cone from the interceptor's heading.

C. Program Capabilities: The program will compute the actual range, range-rate, antenna azimuth and elevation for a radar frame time of two seconds. It will put noise on the above having the standard deviations of 2.5 n.m. for range, 8.72kts for range-rate, 0.745 deg. for azimuth, and 0.86 deg. for elevation. It also puts a half g acceleration noise on the target. It will compute the noisy target location, based on the

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noise. It will further transfer the actual and noisy radar parameters into a moving north, east, down coordinate system which is fixed to move with the interceptor. It will determine whether detection was made or not each frame time, based on a detection probability curve, and perform a quality counter operation which prevents non-detected targets from being smoothed after they are lost for a reasonable number of frames.

D. Input data requirements: Four input cards are required.

1. The first card reads in 16 Hollerith characters which identify the program on the print out and graphs. The format is 2A8.

2. The second card reads in the interceptor's altitude in feet, the target's X and Y coordinates in nautical miles, and altitude in feet, and interceptor and target heading in degrees. The format is 7F6.0.

3. The third card reads in the target and the interceptor's Mach number, the target's maneuver g load capabilities for turn, pull out, and dive, (negative number), and the problem time to target turn and/or dive.

The format is 7F6.2.

4. The fourth card reads in a fixed point number that allows a different starting point for the subroutine RNDEV, and three fixed point ones or zeroes which control the graph output. The first, if zero, suppresses

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the profile curves, the second, if zero, suppresses the smoothed difference plots, and the third, if zero, suppresses the three dimensional rms smoothed difference plot. The format is 4I6.

E. Requirements for reprogramming the smoothing section: The entering arguments of the smoothing and prediction section are RNME, DIRNE, DIRE, DIRDE, and NQC. The suggested statement numbers to use are the 600 series or above 2000.

F. Quality indicators: The primary quality indicator is the three dimension rms smoothed error from the actual position. The three dimensional rms noise error is computed for comparison. The desired smoothing error on the individual quantities is 0.5 n.m. This could give a three dimensional rms smoothed error of as much as 0.875 n.m. The output curves have points plotted indicating these limits.

G. Output: The print out contains the run identification read in, the problem time, the three dimensional rms actual and smoothed error, whether detection was made or not, ND equals one or zero, and the status of the quality counter, NQ. There are nine output curves. They plot the following:

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1. The interceptor and target's actual and noisy positions in the north-east plane.
2. The interceptor position and the target's smoothed position in the north-east plane.
3. The interceptor and target's actual and noisy positions in the north-down plane.
4. The interceptor's position and the smoothed target's position in the north-down plane.
5. The range smoothed differences from actual and the desired limit points, versus time.
6. The north direction cosine smoothed differences from actual and the desired limits points plotted as a function of actual range, versus time.
7. The east direction cosine smoothed differences similar to the north direction cosine curve.
8. The down direction cosine smoothed differences similar to the north direction cosine curve.
9. The three dimensional rms smoothed error from actual and the desired limits points, versus time.

H. Run time: The average run time is between 2 minutes and 30 seconds and 2 minutes and 50 seconds.

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PROGRAM THREE D

THIS PROGRAM COMPUTES THREE DIMENSIONAL INTERCEPTER-TARGET GEOMETRIES FOR THE PURPOSE OF OPTIMIZING VARIOUS PARAMETERS. THE PROGRAM WILL STOP ANY TIME THAT THE TARGET FLIES OUTSIDE OF A 65 DEGREE CONE FROM THE INTERCEPTERS HEADING.

FOUR INPUT CARDS ARE REQUIRED

1. THE FIRST CARD READS IN 16 HOLLERITH CHARACTERS WHICH IDENTIFY THE PROGRAM ON THE PRINT OUT AND GRAPHS. THE FORMAT IS 2A8.
2. THE SECOND CARD READS IN INTERCEPTERS ALTITUDE IN FEET, TARGETS X AND Y COORDINATES IN NAUTICAL MILES AND Z COORDINATE IN FEET, AND INTERCEPTER AND TARGET HEADING IN DEGREES. THE FORMAT IS 7F6.0.
3. THE THIRD CARD READS IN TARGET INTERCEPTER MACH NUMBER, TARGET MANEUVER G LOAD CAPABILITIES FOR TURN PULL OUT AND DIVE (NEGATIVE NUMBER), AND THE PROBLEM TIME TO TARGET TURN AND DIVE. THE FORMAT IS 7F6.2.
4. THE FOURTH CARD READS IN A FIXED POINT NUMBER THAT ALLOWS A DIFFERENT STARTING POINT FOR THE SUBROUTINE RNDEV, AND THREE FIXED POINT ONES OR ZEROS WHICH CONTROL THE GRAPH OUTPUT. THE FIRST IF ZERO SUPPRESSES THE PROFILE CURVES, THE SECOND IF ZERO SUPPRESSES THE SMOOTHED DIFFERENCE PLOTS, AND THE THIRD IF ZERO SUPPRESSES THE 3D RMS SMOOTHED ERROR PLOT. THE FORMAT IS 4I6.

DIMENSION AND READ STATEMENTS

```

DIMENSION T(151),XONM(151),YONM(151),ZONM(151),XTNM(151),YTNM(151)
1,ZTNM(151),RNM(151),ATAD(151),RNME(151),RDOTME(151),ATADE(151),
2,RNMS(151),RDOTM(151),XTNME(151),YTNME(151),ZTNME(151),XTNMS(151),
3,YTNMS(151),ZTNMS(151),IT(12),DIRN(151),DIRE(151),DIRD(151),
4,DIRNE(151),DIREE(151),DIRDE(151),RDDOTE(151),RNMP(151),RDOTMP(151)
5,DIRNS(151),DIRES(151),DIRDS(151),DIRND(151),DIREDD(151),DIRDD(151)
6,DIRNDD(151),DIREDD(151),DIRDDD(151),DIRNP(151),DIREP(151),DIRDP
7(151),EPSID(151),EPSIDE(151),RSMO(151),ANSMO(151),AESMO(151),ADSMO
8(151),ZETA(151),NQ(151),XTSMO(151),YTSMO(151),ZTSMO(151),CIRERR(15
91),AERRP(30),AERRM(30),RERRP(30),RERRM(30),TC(30),RERR(151)
DIMENSION X1(2),Y1(2),Z1(2),X2(2),Y2(2),Z2(2),CERRP(30)
1,XTERR(151),YTERR(151),ZTERR(151),CIRSMO(151),ND(151)
DO 2 J=1,6
READ 100(IT(I),I=5,6)
100 FORMAT(2A8)
READ 11,Z0,XT0NM,YT0NM,ZT0,ZTF,PSIOD,PSITD,TM,OM,GT,GDP,GDN,
1TT,TD,NOISE,NGRAF1,NGRAF2,NGRAF3
11 FORMAT(7F6.0,/,7F6.2,/,4I6)

```

INITIAL CONDITIONS

```

300 T(1)=0.
TC(1)=0.
TA=0.
TS=0.
NERMAX=30
PI=3.14159265
RAD=180./PI
DIVE=-60./RAD
DT=.05
NUMPTS=151
NPRINT=68

```

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```

NQC=1
NQ(1)=0
NQ(0)=0
NCTC=0
F=1.
Q=1.
K=1.
XT0=XT0NM*6076.1
YT0=YT0NM*6076.1
XT=XT0
YT=YT0
ZT=ZT0
PSIT0=PSITD/RAD
PSIO=PSIOD/RAD
PSIT=PSIT0
AT=PSIT0
ATDOT=0.
ATDDOT=0.
BT=0.
BTDOT=0.
BTDDOT=0.
RN1=0.
RN2=0.
RN3=0.
NUNIF=1220703125

```

C TARGET AND INTERCEPTOR VELOCITY COMPUTATIONS

```

VTDOT=0.
IF(ZT0-37000.)63,69,69
63 VT=TM*(1116.-.00398*ZT0)
GO TO 57
69 VT=TM*967.6
57 IF(Z0-37000.)73,74,74
73 VO=OM*(1116.-.00398*Z0)
GO TO 75
74 VO=OM*967.6
75 IF(ZTF-10000.)78,79,79
78 VTF=1340.+0.08*ZTF
DELTAT=(VT-VTF)/56.4
GO TO 58
79 VTF=VT
DELTAT=0.
58 CONTINUE

```

C THIS ALLOWS A VARIATION IN THE RANDOM NUMBER SEQUENCE

```

IF(Noise)109,109,122
122 DO 102 L=1,NOISE
102 CALL RNDEV(NUNIF,DEV)
109 CONTINUE

```

C BEGIN MAIN PROGRAM DO LOOP

```

DO 20 I=1,15

```

C CHECK ITERATION TIME AGAINST RADAR FRAME TIME

```

22 IF(ABSF(TS-TA)-10.E-5)25,25,24

```

C CHECK MANEUVER TIMES AND/OR READ IN MANEUVER CONDITIONS

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```

24 TA=TA+DT
   IF(TA-TT)39,28,28
39 ATDOT=0.
   GO TO 29
28 ATDOT=GT*32.17/VT
29 IF(TA-TD)40,41,41
40 BTDOT=0.
   GO TO 42
41 IF(ZT-ZTF)76,77,77
76 BTDOT=(GDP-1.)*32.17/VT
   GO TO 42
77 BTDOT=(GDN-1.)*32.17/VT
   VTDOT=-56.4
42 IF((PSIT0+PI)-AT)46,46,45
46 ATDOT=0.
   AT=PSIT0+PI
45 IF(BT-DIVE)34,34,35
34 BTDOT=0.
   BT=DIVE
35 IF (F) 201,201,203
203 ZTP0=(1.-COSF(BT))*VT**2/((GDP-1.)*32.17)+ZTF
   IF (ZTP0-ZT)38,37,37
37 IF(F)201,201,200
200 F=F-1.
   VTP0=VT
201 BTDOT=(GDP-1.)*32.17/VTP0
   IF(BT)38,43,43
43 BTDOT=0.
   BT=0.

38 IF(ZT-ZTF)205,205,206
205 ZT=ZTF
206 IF(TA-(TD+DELTAT))51,51,202
202 VTDOT=0.
   VT=VTF

```

C ITERATION OF TARGETS POSITION

```

51 VT=VT+VTDOT*DT+RN1*DT
   AT=AT+ATDOT*DT+RN2*DT**2/2,
   PSIT=AT
   BT=BT+BTDOT*DT+RN3*DT**2/2,

```

C COMPUTE TARGET POSITION

```

XT=XT+VT*COSF(BT)*COSF(AT)*DT
YT=YT+VT*COSF(BT)*SINF(AT)*DT
ZT=ZT+VT*SINF(BT)*DT

```

C RETURN TO START TO CHECK AGAINST RADAR LOOK TIME

```

   GO TO 22
25 TS=TS+2,

```

C COMPUTE INTERCEPTORS POSITION AND ACTUAL RADAR PARAMETERS

```

X0=VO*T(I)*COSF(PSIO)
Y0=VO*T(I)*SINF(PSIO)
R=SQRTF((XT-X0)**2+(YT-Y0)**2+(ZT-Z0)**2)
EPSI=ASINF((Z0-ZT)/R)
IF(PSIO-PI)60,59,59
59 PSIO=PSIO-2.*PI

```

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PHILOSOPHY 110

PHILOSOPHY 111

PHILOSOPHY 112

PHILOSOPHY 113

PHILOSOPHY 114

PHILOSOPHY 115

PHILOSOPHY 116

```

60 IF(YT-YO)31,32,32
31 ATA=-ACOSF((XT-XO)/(R*COSF(EPSI)))-PSIO
GO TO 33
32 ATA=ACOSF((XT-XO)/(R*COSF(EPSI)))-PSIO

```

C ? CHECK IF TARGET IS STILL IN RADAR BEAM, IF NOT STOP

```

33 IF(ATA-1.1345)26,26,50
26 IF(ATA+1.1345)50,49,49
49 IF(EPSI-1.1345)48,48,50
48 IF(EPSI+1.1345)50,27,27
50 NUMPTS=(I-1)
   NERMAX=NUMPTS/10
   NPLOT=NUMPTS-NCTC
   IF(NUMPTS-68)15,14,14
15 NPRINT=NUMPTS
14 GO TO 1
27 RDOT=-VT*COSF(PSIT-ACOSF((XT-XO)/(R*COSF(EPSI)))+PI)*COSF(EPSI)
   1-V0*COSF(ATA)*COSF(EPSI)

```

C CONVERT ACTUAL RADAR PARAMETERS TO KTS, NM/SEC, DEG

```

RNM(I)=R/6076.1
ATAD(I)=ATA*RAD
EPSID(I)=EPSI*RAD
RDOTM(I)=RDOT/6076.1
XONM(I)=XO/6076.1
YONM(I)=YO/6076.1
ZONM(I)=ZO/6076.1
XTNM(I)=XT/6076.1
YTNM(I)=YT/6076.1
ZTNM(I)=ZT/6076.1

```

C OBTAIN TARGET MANEUVER NOISE

```

CALL RNDEV(NUNIF,DEV)
RN1=16.*DEV
CALL RNDEV(NUNIF,DEV)
RN2=16./VT*DEV
CALL RNDEV(NUNIF,DEV)
RN3=16./VT*DEV

```

C OBTAIN NOISY RADAR PARAMETERS AND CONVERT TO CONVENIENT UNITS

```

CALL RNDEV(NUNIF,DEV)
ATAE=ATA+.013*DEV
CALL RNDEV(NUNIF,DEV)
RE=R+15000.*DEV
CALL RNDEV(NUNIF,DEV)
EPSIE=EPSI+.015*DEV
CALL RNDEV(NUNIF,DEV)
RDOTE=RDOT+14.7174*DEV
ATADE(I)=ATAE*RAD
EPSIDE(I)=EPSIE*RAD
RNME(I)=RE/6076.1
RDOTME(I)=RDOTE/6076.1

```

C COMPUTE NOISY TARGET SPACE STABILIZED POSITION

```

IF(PSIO-1.)70,70,71
70 XTE=XO+RE*COSF(ATAE+PSIO)*COSF(EPSIE)
   YTE=YO+RE*SINF(ATAE+PSIO)*COSF(EPSIE)

```

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GO TO 72
 71 XTE=XO+RE*COSF(ATAE-PSIO)*COSF(EPSIE)
 YTE=YO+RE*SINF(ATAE-PSIO)*COSF(EPSIE)
 72 ZTE=ZO-RE*SINF(EPSIE)
 XTNME(I)=XTE/6076.1
 YTNME(I)=YTE/6076.1
 ZTNME(I)=ZTE/6076.1

C COMPUTE ACTUAL DIRECTION COSINES FOR INTERCEPTOR WITH ROLL
 C AND PITCH ZERO

DIRN(I)=COSF(ATA)*COSF(PSIO)-SINF(ATA)*SINF(PSIO)
 DIRE(I)=COSF(ATA)*SINF(PSIO)+SINF(ATA)*COSF(PSIO)
 DIRD(I)=-SINF(EPSI)

C COMPUTE NOISY DIRECTION COSINES

DIRNE(I)=COSF(ATAE)*COSF(PSIO)-SINF(ATAE)*SINF(PSIO)
 DIREE(I)=COSF(ATAE)*SINF(PSIO)+SINF(ATAE)*COSF(PSIO)
 DIRDE(I)=-SINF(EPSIE)

C OBTAIN DETECTION PROBABILITY AND DETERMINE IF TARGET WAS
 C DETECTED

CALL RNDEV (NUNIF,DEV)
 IF(RNM(I)-20.)21,23,23
 21 PD=2.36-.043*RNM(I)
 GOTO 52
 23 IF (RNM(I)-50.)36,47,47
 36 PD=1.95-.0239*RNM(I)
 GO TO 52
 47 IF (RNM(I)-80.)65,66,66
 65 PD=1.55-.016*RNM(I)
 GO TO 52
 66 IF (RNM(I)-110.)62,68,68
 62 PD=.88-.0077*RNM(I)
 GO TO 52
 68 PD=.25-.0019*RNM(I)
 52 CONTINUE
 ADEV=ABSF(DEV)
 IF(PD-ADEV)53,54,54

C QUALITY COUNTER COMPUTATIONS

53 ND(I)=0
 NQ(I)=NQ(I-1)-1
 IF (NQ(I))250,151,152
 250 NQ(I)=0
 GO TO 151
 54 ND(I)=1
 NQ(I)=NQ(I-1)+2
 IF (10-NQ(I))251,153,153
 251 NQ(I)=10
 GO TO 153

C SMOOTHING AND PREDICTION SECTION

C NO DETECTION CONDITIONS

C IF QUALITY COUNTER IS ZERO PRINT THE FOLLOWING AND START NEXT
 C FRAME TIME

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NOT POSTED


```

151 CIRERR(I)=999.9999
    CIRSMO(I)=999.9999
    XTNMS(I)=XTNM(I)
    YTNMS(I)=YTNM(I)
    ZTNMS(I)=ZTNM(I)
    ND(I)=99
    NQC=1
GO TO 20

```

C IF QUALITY COUNTER IS NON ZERO ERROR VALUES EQUAL PREDICTED
C ONES, COMPUTE ONLY NEXT PREDICTED VALUES

```

152 RNME(I)=RNMP(I)
    RDOTME(I)=RDOTMP(I)
    DIRNE(I)=DIRNP(I)
    DIREE(I)=DIREP(I)
    DIRDE(I)=DIRDP(I)
GO TO 61

```

C DETECTION CONDITIONS

```

153 IF (NQC)61,61,154

```

C INITIAL CONTACT CONDITIONS AT START OR AFTER CONTACT HAS
C BEEN LOST AND REGAINED

```

154 NQC=NQC-1
    RNMP(I)=RNME(I)
    RDOTMP(I)=RDOTME(I)
    DIRNP(I)=DIRNE(I)
    DIREP(I)=DIREE(I)
    DIRDP(I)=DIRDE(I)
    RDDOTE(I-1)=0.
    DIRND(I-1)=0.
    DIRNDD(I-1)=0.
    DIRED(I-1)=0.
    DIREDD(I-1)=0.
    DIRDD(I-1)=0.
    DIRDDD(I-1)=0.

```

```

61 CONTINUE

```

C SMOOTHING CONSTANT COMPUTATIONS

```

ALPHAR=.45
ALPHAN=.43
BETAN=ALPHAN**2/(2.-ALPHAN)
GAMMAN=2.*BETAN/ALPHAN-(ALPHAN+BETAN)
ALPHAЕ=ALPHAN
ALPHAD=.35
BETAD=ALPHAD**2/(2.-ALPHAD)
GAMMAD=2.*BETAD/ALPHAD-(ALPHAD+BETAD)

```

C SMOOTHING AND PREDICTION COMPUTATIONS

```

C RANGE
RNMS(I)=RNMP(I)+ALPHAR*(RNME(I)-RNMP(I))
RDDOTE(I)=RDDOTE(I-1)+1./(2.*Q)*(RDOTME(I)-RDOTMP(I))
RNMP(I+1)=RNMS(I)+2.*RDOTME(I)+2.*RDDOTE(I)
RDOTMP(I+1)=RDOTME(I)+2.*RDDOTE(I)

```

C NORTH DIRECTION COSINE

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```

DIRNS(I)=DIRNP(I)+ALPHAN*(DIRNE(I)-DIRNP(I))
DIRND(I)=DIRND(I-1)+2.*DIRNDD(I-1)+BETAN/2.*(DIRNE(I)-DIRNP(I))
DIRNDD(I)=DIRNDD(I-1)+2.*GAMMAN/4.*(DIRNE(I)-DIRNP(I))
DIRNP(I+1)=DIRNS(I)+2.*DIRND(I)+2.*DIRNDD(I)

```

C

3 EAST DIRECTION COSINE

```

DIREP(I)=DIREP(I)+ALPHAN*(DIREE(I)-DIREP(I))
DIREDD(I)=DIREDD(I-1)+2.*DIREDD(I-1)+BETAN/2.*(DIREE(I)-DIREP(I))
DIREDD(I)=DIREDD(I-1)+2.*GAMMAN/4.*(DIREE(I)-DIREP(I))
DIREP(I+1)=DIREP(I)+2.*DIREDD(I)+2.*DIREDD(I)

```

C

DOWN DIRECTION COSINE

```

DIRDP(I)=DIRDP(I)+ALPHAD*(DIRDE(I)-DIRDP(I))
DIRDD(I)=DIRDD(I-1)+2.*DIRDD(I-1)+BETAD/2.*(DIRDE(I)-DIRDP(I))
DIRDD(I)=DIRDD(I-1)+2.*GAMMAD/4.*(DIRDE(I)-DIRDP(I))
DIRDP(I+1)=DIRDS(I)+2.*DIRDD(I)+2.*DIRDD(I)

```

C

COMPUTE SMOOTHED TARGET POSITION

```

ZETA(I)=ACOSF(DIRDS(I))-PI/2.
XTNMS(I)=XONM(I)+RNMS(I)*COSF(ZETA(I))*DIRNS(I)
YTNMS(I)=YONM(I)+RNMS(I)*COSF(ZETA(I))*DIREP(I)
ZTNMS(I)=ZONM(I)+DIRDS(I)*RNMS(I)

```

C

COMPUTE SMOOTHED AND ERROR DIFFERENCES FROM ACTUAL

```

XTSMO(I)=XTNM(I)-XTNMS(I)
YTSMO(I)=YTNM(I)-YTNMS(I)
ZTSMO(I)=ZTNM(I)-ZTNMS(I)
XTERR(I)=XTNM(I)-XTNME(I)
YTERR(I)=YTNM(I)-YTNME(I)
ZTERR(I)=ZTNM(I)-ZTNME(I)
RSMO(I)=RNM(I)-RNMS(I)

```

C

COMPUTE THE ACTUAL AND SMOOTHED 3D RMS ERROR VALUES

```

CIRERR(I)=SQRTF(XTERR(I)**2+YTERR(I)**2+ZTERR(I)**2)
CIRSMO(I)=SQRTF(XTSMO(I)**2+YTSMO(I)**2+ZTSMO(I)**2)

```

C

CHECK TO SEE IF THE ACOSF ARGUMENT HAS BEEN EXCEEDED,

C

IF IT HAS SET THE COSINE EQUAL TO ONE AND PRINT OUT THE VALUE

```

IF (DIRNS(I)-1.)211,211,210
210 PRINT 212,(T(I),DIRNS(I))
212 FORMAT(6X2HT=F8.4,2X6HDIRNS=F8.4)
DIRNS(I)=1.0
211 IF (DIREP(I)-1.)221,221,220
220 PRINT 222,(T(I),DIREP(I))
222 FORMAT(6X2HT=F8.4,2X6HDIREP=F8.4)
DIREP(I)=1.0
221 IF (DIRDS(I)-1.)231,231,230
230 PRINT 232,(T(I),DIRDS(I))
232 FORMAT(6X2HT=F8.4,2X6HDIRDS=F8.4)
DIRDS(I)=1.0
231 CONTINUE

```

C

CONVERT THE DIRECTION COSINES TO DEGREES FOR GRAPH OUTPUT

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```

ANSMO(I)=ACOSF(DIRN(I))-ACOSF(DIRNS(I))
AESMO(I)=ACOSF(DIRE(I))-ACOSF(DIRES(I))
ADSMO(I)=ACOSF(DIRD(I))-ACOSF(DIRDS(I))

```

C COMPUTE THE DESIRED LIMIT POINTS FOR THE GRAPH OUTPUTS

```

120 IF (T(K)-T(I))120,120,121

```

```

120 TC(K+1)=TC(K)+10.

```

```

AERRP(K)=ATANF(.5/RNM(I))

```

```

AERRM(K)=-AERRP(K)

```

```

RERRP(K)=.5

```

```

RERRM(K)=-.5

```

```

CERRP(K)=.875

```

```

K=K+1

```

```

121 CONTINUE

```

C IF DETECTION WAS MISSED INCREASE Q IN THE RDOT SMOOTHING
C COMPUTATIONS

```

IF (ND(I))55,55,56

```

```

55 Q=Q+1.

```

```

GO TO 20

```

```

56 Q=1.

```

```

20 T(I+1)=T(I)+2.

```

C END OF MAIN PROGRAM DO LOOP

```

1 CONTINUE

```

C OUTPUT CONTROL

C COMPUTE MARKERS WHICH INDICATE THE TARGETS INITIAL POSITION
C ON THE SMOOTHED PROFILE CURVES

```

X1(1)=XT0NM+.5

```

```

X1(2)=XT0NM-.5

```

```

Y1(1)=YT0NM+.5

```

```

Y1(2)=YT0NM-.5

```

```

Z1(1)=ZT0/6076.1+.05

```

```

Z1(2)=ZT0/6076.1-.05

```

```

X2(1)=XT0NM+.5

```

```

X2(2)=XT0NM-.5

```

```

Y2(1)=YT0NM+.5

```

```

Y2(2)=YT0NM-.5

```

```

Z2(1)=ZT0/6076.1-.05

```

```

Z2(2)=ZT0/6076.1+.05

```

C GRAPH STATEMENTS

```

IF (NGRAF1)270,270,271

```

```

- 271 CONTINUE

```

```

DO 101 I=1,4

```

```

101 IT(I)=8H

```

```

IT(1)=8HGENTZ NE

```

```

IT(2)=8H PLANE A

```

```

IT(3)=8HCTUAL;+

```

```

IT(4)=8HNOISE

```

```

I=1

```

```

CALL DRAW(NUMPTS,Y0NM,X0NM,1,0,4H ,IT,15.,15.,0,3,2,2,6,6,1,

```

```

1LAST)

```

```

CALL DRAW(NUMPTS,YTNM,XTNM,2,0,4H )

```

```

CALL DRAW(NUMPTS,YTNME,XTNME,3,0,4H )

```

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```

DO 103 I=1,4
103 IT(I)=8H
IT(1)=8HGENTZ NE
IT(2)=8H PLANE S
IT(3)=8HMOOTHED
IT(4)=8HPOSITION
I=1
CALL DRAW(NUMPTS,YONM,XONM,1,0,4H ,IT,15,,15,,0,3,2,2,6,6,1,
1LAST)
CALL DRAW(NUMPTS,YTNMS,XTNMS,2,0,4H )
CALL DRAW (2,Y1,X1,2,0,4H )
CALL DRAW (2,Y2,X2,3,0,4H )
DO 104 I=1,4
104 IT(I)=8H
IT(1)=8HGENTZ ND
IT(2)=8H PLANE A
IT(3)=8HCTUAL +
IT(4)=8HNOISE
I=1
CALL DRAW(NUMPTS,XONM,ZONM,1,0,4H ,IT,15,,1.5,0,0,2,2,6,6,1 ,
1LAST)
CALL DRAW(NUMPTS,XTNM,ZTNM,2,0,4H )
CALL DRAW(NUMPTS,XTNME,ZTNME,3,0,4H )
DO 110 I=1,4
110 IT(I)=8H
IT(1)=8HGENTZ ND
IT(2)=8H PLANE S
IT(3)=8HMOOTHED
IT(4)=8HPOSITION
I=1
CALL DRAW(NUMPTS,XONM,ZONM,1,0,4H ,IT,15,,1.5,0,0,2,2,6,6,1 ,
1LAST)
CALL DRAW(NUMPTS,XTNMS,ZTNMS,2,0,4H )
CALL DRAW(2,X1,Z1,2,0,4H )
CALL DRAW (2,X2,Z2,3,0,4H )
270 CONTINUE
IF (NGRAF2)281,281,282
282 CONTINUE
DO 105 I=1,4
105 IT(I)=8H
IT(1)=8HGENTZ RA
IT(2)=8HNGE SMOO
IT(3)=8HTHING RE
IT(4)=8HSULTS
I=1
CALL DRAW(NUMPTS,T,RSMO,1,0,4H ,IT,50,,1,,3,0,2,2,6,6,1,LAST)
CALL DRAW(NERMAX,TC,RERRP,2,2,4H )
CALL DRAW(NERMAX,TC,RERRM,3,2,4H )
DO 106 I=1,4
106 IT(I)=8H
IT(1)=8HGENTZ NO
IT(2)=8HRTH SMOO
IT(3)=8HTHING RE
IT(4)=8HSULTS
I=1
CALL DRAW(NUMPTS,T,ANSMO,1,0,4H ,IT,50,,.01,3,0,2,2,6,6,1,LAST)
CALL DRAW(NERMAX,TC,AERRP,2,2,4H )
CALL DRAW(NERMAX,TC,AERRM,3,2,4H )
DO 116 I=1,4
116 IT(I)=8H
IT(1)=8HGENTZ EA
IT(2)=8HST SMOOT

```

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```
IT(3)=8HHING RES
IT(4)=8HULTS
I=1
CALL DRAW(NUMPTS,T,AESMO,1,0,4H ,IT,50...01,3,0,2,2,6,6,1, LAST)
CALL DRAW(NERMAX,TC,AERRP,2,2,4H )
CALL DRAW(NERMAX,TC,AERRM,3,2,4H )
DO 108 I=1,4
108 IT(I)=8H
IT(1)=8HGENTZ DO
IT(2)=8HWN SMOOT
IT(3)=8HHING RES
IT(4)=8HULTS
I=1
CALL DRAW(NUMPTS,T,ADSMO,1,0,4H ,IT,50...01,3,0,2,2,6,6,1, LAST)
CALL DRAW(NERMAX,TC,AERRP,2,2,4H )
CALL DRAW(NERMAX,TC,AERRM,3,2,4H )
281 CONTINUE
IF (NGRAF3)283,283,284
284 CONTINUE
DO 285 I=1,4
285 IT(I)=8H
IT(1)=8HGENTZ 3D
IT(2)=8H RMS SMO
IT(3)=8HOTHING R
IT(4)=8HESULTS
I=1
CALL DRAW(NUMPTS,T,CIRSMO,1,0,4H ,IT,50...5,0,0,2,2,6,6,1,
1LAST)
CALL DRAW(NERMAX,TC,CERRP,3,2,4H )
283 CONTINUE
```

C PRINT STATEMENTS

```
PRINT 95
95 FORMAT(1H1,27X17HSMOOTHING RESULTS)
PRINT 64,(IT(I),I=5,6)
64 FORMAT(/,32X,2A8)
PRINT 107
107 FORMAT( /,6X66HT=TIME, R NM=ACTUAL RANGE, CIRERR=3DIMENSIONAL RMS
1 ACTUAL ERROR, /,6X64HCIRSMO=3 DIMENSIONAL RMS SMOOTHED ERROR
2, ND=1 DETECTION, ND=0 NO,/,6X 68HDETECTION, NQ=QUALITY COUNTER, W
3HEN NQ=0 TARGET CONSIDERED LOST AND /,6X24HALL NINES ARE PRINTED.
4 )
PRINT 96
96 FORMAT( /,15X1HT,4X4HR NM,7X6HCIRERR,4X6HCIRSMO,2X2HND,
12X2HNQ)
PRINT 97,(T(I),RNM(I),CIRERR(I),CIRSMO(I),ND(I),NQ(I),I=1,NUMPTS)
97 FORMAT ( 7X,1F10.0,3F10.4,2I4)
2 CONTINUE
400 STOP
END
END
```

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Appendix C

Computer Program of Program ALPHA CHECK

Only the smoothing and prediction and output sections are shown since the preceeding portions are the same as in THREE D.

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2. 1. 1998

3. 1. 1998

4. 1. 1998

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```

47 IF (RNM(I)-80.)65,66,66
65 PD=1.55-.016*RNM(I)
GO TO 52
66 IF (RNM(I)-110.)62,68,68
62 PD=.88-.0077*RNM(I)
GO TO 52
68 PD=.25+.0019*RNM(I)
52 CONTINUE
ADEV=ABSF(DEV)
ADEV=0.
IF(PD-ADEV)53,54,54
53 NQ(I)=0
GO TO 20
54 NQ(I)=1
20 T(I+1)=T(I)+2.
1 CONTINUE

```

C SMOOTHING COMPUTATIONS

```

FPTS=NUMPTS
NALPH=20

```

C RANGE SMOOTHING CONSTANT ANALYSIS

```

ALPHAR=.05
DO 301 J=1,NALPH
P=1.
AR(J)=ALPHAR
ERAR(J)=0.
DO 305 I=1,NUMPTS
IF (NQ(I))302,302,303
302 IF(P)304,304,305
304 RNME(I)=RNMP(I)
RDOTME(I)=RDOTMP(I)
GO TO 306
303 IF(P)306,306,308
308 P=P-1.
CTC=T(I)/2.+1.
RNMP(I)=RNME(I)
RDOTMP(I)=RDOTME(I)
RDDOTE(I-1)=0.
306 RDDOTE(I)=RDDOTE(I-1)+1./(2.*Q)*(RDOTME(I)-RDOTMP(I))
RNMS(I)=RNMP(I)+ALPHAR*(RNME(I)-RNMP(I))
RNMP(I+1)=RNMS(I)+2.*RDOTME(I)+2.*RDDOTE(I)
RDOTMP(I+1)=RDOTME(I)+2.*RDDOTE(I)
RSMO(I)=(RNM(I)-RNMS(I))*2
ERAR(J)=ERAR(J)+RSMO(I)/(FPTS-CTC)
IF(NQ(I)) 55,55,56
55 Q=Q+1.
GO TO 305
56 Q=1.
305 CONTINUE
301 ALPHAR=ALPHAR+.05
I=1
PRINT 114
114 FORMAT(1H1,17X,6HOPTIMUM,SMOOTHING CONSTANT ANALYSIS,/,6X62HQUAL
1TY INDICATOR,THE MINIMUM AVERAGE MEAN SQUARE ERROR )
PRINT 604,((IT(I),I=5,6),ANOISE)
604 FORMAT(/,20X,2A8,2X7HANOISE=F4.2)
PRINT 115
115 FORMAT(/,29X16HRANGE, ALPHAR )
PRINT 116,(AR(J),ERAR(J),J=1,NALPH)

```

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116 FORMAT(/,((23X7HALPHAR= F4.2,2X5HERAR= F6.4)/))

C NORTH DIRECTION COSINE SMOOTHING CONSTANT ANALYSIS

```

ALPHAN=.05
DO 321 K=1,NALPH
P=1.
AN(K)=ALPHAN
ERAN(K)=0.
BETAN=ALPHAN**2/(2.-ALPHAN)
GAMMAN=2.*BETAN/ALPHAN-(ALPHAN+BETAN)
DO 325 I=1,NUMPTS
IF(NQ(I))322,322,323
322 IF(P)324,324,325
324 DIRNE(I)=DIRNP(I)
GO TO 326
323 IF(P)326,326,328
328 P=P-1.
DIRNP(I)=DIRNE(I)
DIRND(I-1)=0.
DIRNDD(I-1)=0.
326 DIRND(I)=DIRND(I-1)+2.*DIRNDD(I-1)+BETAN/2.*(DIRNE(I)-DIRNP(I))
DIRNDD(I)=DIRNDD(I-1)+2.*GAMMAN/4.*(DIRNE(I)-DIRNP(I))
DIRNS(I)=DIRNP(I)+ALPHAN*(DIRNE(I)-DIRNP(I))
DIRNP(I+1)=DIRNS(I)+2.*DIRND(I)+2.*DIRNDD(I)
DNSMO(I)=(DIRN(I)-DIRNS(I))**2
ERAN(K)=ERAN(K)+DNSMO(I)/(FPTS-CTC)
325 CONTINUE
321 ALPHAN=ALPHAN+.05
I=1
PRINT 117
117 FORMAT(/,20X31HNORTH DIRECTION COSINE, ALPHAN)
PRINT 118,(AN(K),ERAN(K),K=1,NALPH)
118 FORMAT(/,((23X7HALPHAN= F4.2,2X5HERAN= F10.8)/))

```

C EAST DIRECTION COSINE SMOOTHING CONSTANT ANALYSIS

```

ALPHAE=.05
DO 331 L=1,NALPH
P=1.
AE(L)=ALPHAE
BETAE=ALPHAE**2/(2.-ALPHAE)
GAMMAE=2.*BETAE/ALPHAE-(ALPHAE+BETAE)
ERAEL=0.
DO 335 I=1,NUMPTS
IF (NQ(I))332,332,333
332 IF(P)334,334,335
334 DIREP(I)=DIREE(I)
GO TO 336
333 IF(P)336,336,338
338 P=P-1.
DIREP(I)=DIREE(I)
DIREL(I-1)=0.
DIREDD(I-1)=0.
336 DIREL(I)=DIREL(I-1)+2.*DIREDD(I-1)+BETAE/2.*(DIREE(I)-DIREP(I))
DIREDD(I)=DIREDD(I-1)+2.*GAMMAE/4.*(DIREE(I)-DIREP(I))
DIRES(I)=DIREP(I)+ALPHAE*(DIREE(I)-DIREP(I))
DIREP(I+1)=DIRES(I)+2.*DIREL(I)+2.*DIREDD(I)
DESMO(I)=(DIRE(I)-DIRES(I))**2
ERAEL=ERAEL+DESMO(I)/(FPTS-CTC)
335 CONTINUE
331 ALPHAE=ALPHAE+.05

```


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```

      I=1
      PRINT 119
119  FORMAT(1H1,20X31H EAST DIRECTION COSINE, ALPHAE
      PRINT 161,(AE(L), ERAE(L), L=1, NALPH)
161  FORMAT(/, ((23X7HALPHAE= F4.2, 2X5HERAE= F10.8)))

C      : DOWN DIRECTION COSINE SMOOTHING CONSTANT ANALYSIS
      ALPHAD=.05
      DO 341 M=1, NALPH
      P=1.
      AD(M)=ALPHAD
      BETAD=ALPHAD**2/(2.-ALPHAD)
      GAMMAD=2.*BETAD/ALPHAD-(ALPHAD+BETAD)
      ERAD(M)=0.
      DO 345 I=1, NUMPTS
      IF(NQ(I))342,342,343
342  IF(P)344,344,345
344  DIRDE(I)=DIRDP(I)
      GO TO 346
343  IF(P)346,346,348
348  P=P-1.
      DIRDP(I)=DIRDE(I)
      DIRDD(I-1)=0.
      DIRDDD(I-1)=0.
346  DIRDD(I)=DIRDD(I-1)+2.*DIRDDD(I-1)+BETAD/2.*(DIRDE(I)-DIRDP(I))
      DIRDDD(I)=DIRDDD(I-1)+2.*GAMMAD/4.*(DIRDE(I)-DIRDP(I))
      DIRDS(I)=DIRDP(I)+ALPHAD*(DIRDE(I)-DIRDP(I))
      DIRDP(I+1)=DIRDS(I)+2.*DIRDD(I)+2.*DIRDDD(I)
      DDSMO(I)=(DIRD(I)-DIRDS(I))**2
      ERAD(M)=ERAD(M)+DDSMO(I)/(FPTS-CTC)
345  CONTINUE
341  ALPHAD=ALPHAD+.05
      I=1
      PRINT 121
121  FORMAT(/,20X31HDOWN DIRECTION COSINE, ALPHAD )
      PRINT 123,(AD(M), ERAD(M), M=1, NALPH)
123  FORMAT(/, ((23X7HALPHAD= F4.2, 2X5HERAD= F10.8)))
      IF (NGRAPH)270,270,271
271  CONTINUE
      DO 110 I=1, 4
110  IT(I)=8H
      IT(1)=8HGENTZ AL
      IT(2)=8HPHAR VS
      IT(3)=8HAVG MEAN
      IT(4)=8HSQ ERROR
      I=1
      CALL DRAW(NALPH, AR, ERAR, 0, 0, 4H , IT, .2, 0., 0, 0, 2, 2, 5, 6, 1, LAST)
      DO 111 I=1, 4
111  IT(I)=8H
      IT(1)=8HGENTZ AL
      IT(2)=8HPHAN VS
      IT(3)=8HAVG MEAN
      IT(4)=8HSQ ERROR
      I=1
      CALL DRAW(NALPH, AN, ERAN, 0, 0, 4H , IT, .2, 0., 0, 0, 2, 2, 5, 6, 1, LAST)
      DO 112 I=1, 4
112  IT(I)=8H
      IT(1)=8HGENTZ AL
      IT(2)=8HPPAE VS
      IT(3)=8HAVG MEAN
      IT(4)=8HSQ ERROR

```

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APPENDIX C

```
I=1
CALL DRAW(NALPH,AE,ERAЕ,0,0,4H      ,IT,.2,0.,0,0,2,2,5,6,1,LAST)
DO 113 I=1,4
113 IT(I)=8H.
IT(1)=8H GENTZ AL
IT(2)=8H PHAD VS
IT(3)=8H AVG MEAN
IT(4)=8H SQ ERROR
I=1
CALL DRAW(NALPH,AD,ERAD,0,0,4H      ,IT,.2,0.,0,0,2,2,5,6,1,LAST)
270 CONTINUE
ANOISE=ANOISE+.5
2 CONTINUE
END
END
```

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Appendix C

Results of Runs 2A and 3A

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SMOOTHING RESULTS

RUN 2A

T=TIME, R NM=ACTUAL RANGE, CIRERR=3DIMENSIONAL RMS ACTUAL ERROR,
CIRSMO=3 DIMENSIONAL RMS SMOOTHED ERROR, ND=1 DETECTION, ND=0 NO
DETECTION, NQ=QUALITY COUNTER, WHEN NQ=0 TARGET CONSIDERED LOST AND
ALL NINES ARE PRINTED.

T	R NM	CIRERR	CIRSMO	ND	NQ
.	14.1508	.2429	.2429	1	2
2.	14.5361	1.8578	.1884	0	1
4.	14.9288	5.1681	2.3338	1	3
6.	15.3280	2.6577	2.4972	1	5
8.	15.7357	.2391	1.3032	1	7
10.	16.1530	3.2430	2.1581	1	9
12.	16.5815	.5384	1.3833	1	10
14.	17.0281	2.8164	.5864	1	10
16.	17.4867	.2840	.4138	1	10
18.	17.9446	3.1760	1.2653	1	10
20.	18.4155	.3837	.6776	1	10
22.	18.8975	1.3631	1.0167	1	10
24.	19.3867	.2607	.4953	1	10
26.	19.8780	.3462	.2626	1	10
28.	20.3618	1.0472	.4439	1	10
30.	20.8512	.4633	.4537	1	10
32.	21.3431	.8665	.6507	1	10
34.	21.8341	3.2078	1.2478	1	10
36.	22.3337	2.3855	.5537	1	10
38.	22.8417	.6766	.2386	1	10
40.	23.3525	2.2829	1.0736	1	10
42.	23.8669	.4162	.7837	1	10
44.	24.3896	.8367	.4905	1	10
46.	24.9098	2.7580	1.1853	1	10
48.	25.4187	1.8427	.4945	1	10
50.	25.9207	1.8184	.8741	1	10
52.	26.4281	2.0666	1.4061	1	10
54.	26.9446	.1707	.7198	1	10
56.	27.4663	.3516	.3665	1	10
58.	27.9841	2.4726	1.2136	1	10
60.	28.4961	2.8985	1.9486	1	10
62.	29.0163	.9102	.8421	1	10
64.	29.5405	2.4250	1.5345	1	10
66.	30.0547	.2888	.7757	1	10
68.	30.5636	2.8572	1.0178	1	10
70.	31.0732	1.1682	.7910	1	10
72.	31.5752	2.5874	.9229	1	10
74.	32.0719	4.1386	.9257	0	9
76.	32.5737	4.3305	.9190	0	8
78.	33.0744	.7393	.2930	1	10
80.	33.5744	.4837	.2606	1	10
82.	34.0735	3.1434	1.3395	1	10
84.	34.5622	6.2619	2.0776	1	10
86.	35.0347	1.3708	1.6499	1	10
88.	35.4993	1.3935	.3853	1	10
90.	35.9716	2.2291	1.1751	1	10
92.	36.4471	.8413	.9765	1	10
94.	36.9205	4.1630	1.0170	0	9
96.	37.4029	.7908	1.0545	0	8
98.	37.8898	2.9077	1.8114	1	10
100.	38.3598	2.2822	1.9747	1	10

102.	38.8208	1.2352	1.6414	1	10
104.	39.2771	1.0081	1.6821	0	9
106.	39.7219	1.3226	1.7492	0	8
108.	40.1699	2.5017	.6377	1	10
110.	40.6274	1.5599	.7224	0	9
112.	41.0975	1.1474	.3996	1	10
114.	41.5831	2.4063	.9575	1	10
116.	42.0766	2.8075	1.7263	2	13
118.	42.5788	2.0830	1.8448	1	10
120.	43.0949	1.6373	1.0452	1	10
122.	43.6149	3.9712	1.5931	1	10
124.	44.1265	3.5972	.9488	1	10
126.	44.6289	1.1772	.9773	1	10
128.	45.1289	2.5394	1.0695	0	9
130.	45.6308	4.0954	1.6265	1	10
132.	46.1254	3.1991	1.6298	0	9
134.	46.6149	3.7560	1.6372	0	8
136.	47.1069	1.7349	.4193	1	10
138.	47.6015	4.5316	.5815	0	9
140.	48.1068	1.5873	.7846	1	10
142.	48.6124	3.4682	.9627	0	9
144.	49.1099	4.5222	1.9443	1	10
146.	49.6123	2.4393	1.9411	1	10
148.	50.1305	1.1182	1.4023	1	10
150.	50.6560	2.0418	1.1725	1	10
152.	51.1413	1.4302	.9893	1	10
154.	51.5500	3.1677	.9586	0	9
156.	51.8594	5.5666	2.8916	1	10
158.	52.0482	4.1646	.2635	1	10
160.	52.1140	1.8953	.8238	1	10
162.	52.0591	3.4264	2.0061	1	10
164.	51.9006	5.1728	1.1369	1	10
166.	51.6697	1.1559	1.0252	1	10
168.	51.3834	5.7135	1.0221	0	9
170.	51.0395	.6025	.6973	1	10
172.	50.6556	1.1781	.9878	1	10
174.	50.2446	2.0658	1.2707	0	9
176.	49.8208	4.6100	1.2732	1	10
178.	49.3989	3.2128	2.0423	1	10
180.	48.9821	4.2528	1.9403	0	9
182.	48.5692	1.0591	1.3613	1	10
184.	48.1119	2.1753	1.4066	0	9
186.	47.5735	2.5240	1.5005	0	8
188.	46.9689	2.4412	1.3493	1	10
190.	46.3166	.7867	1.3113	0	9
192.	45.6382	1.7295	1.2334	1	10
194.	44.9558	.9434	.6980	1	10
196.	44.2740	.4483	.5947	1	10
198.	43.5920	2.8470	.7076	0	9
200.	42.9103	1.1029	.9519	1	10
202.	42.2292	2.2757	1.1051	0	9
204.	41.5480	1.7588	.9635	1	10
206.	40.8671	2.3066	.9918	0	9
208.	40.1867	3.8105	2.1570	1	10
210.	39.5063	3.1534	2.1457	0	9
212.	38.8259	1.9573	.7847	1	10
214.	38.1456	1.5807	1.0460	2	13
216.	37.4664	1.3193	1.0607	0	9
218.	36.7869	.5547	1.0738	0	8
220.	36.1085	1.0087	.2027	1	10
222.	35.4303	2.1346	.8276	1	10
224.	34.7529	1.3110	1.0649	1	10

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TABLE VI

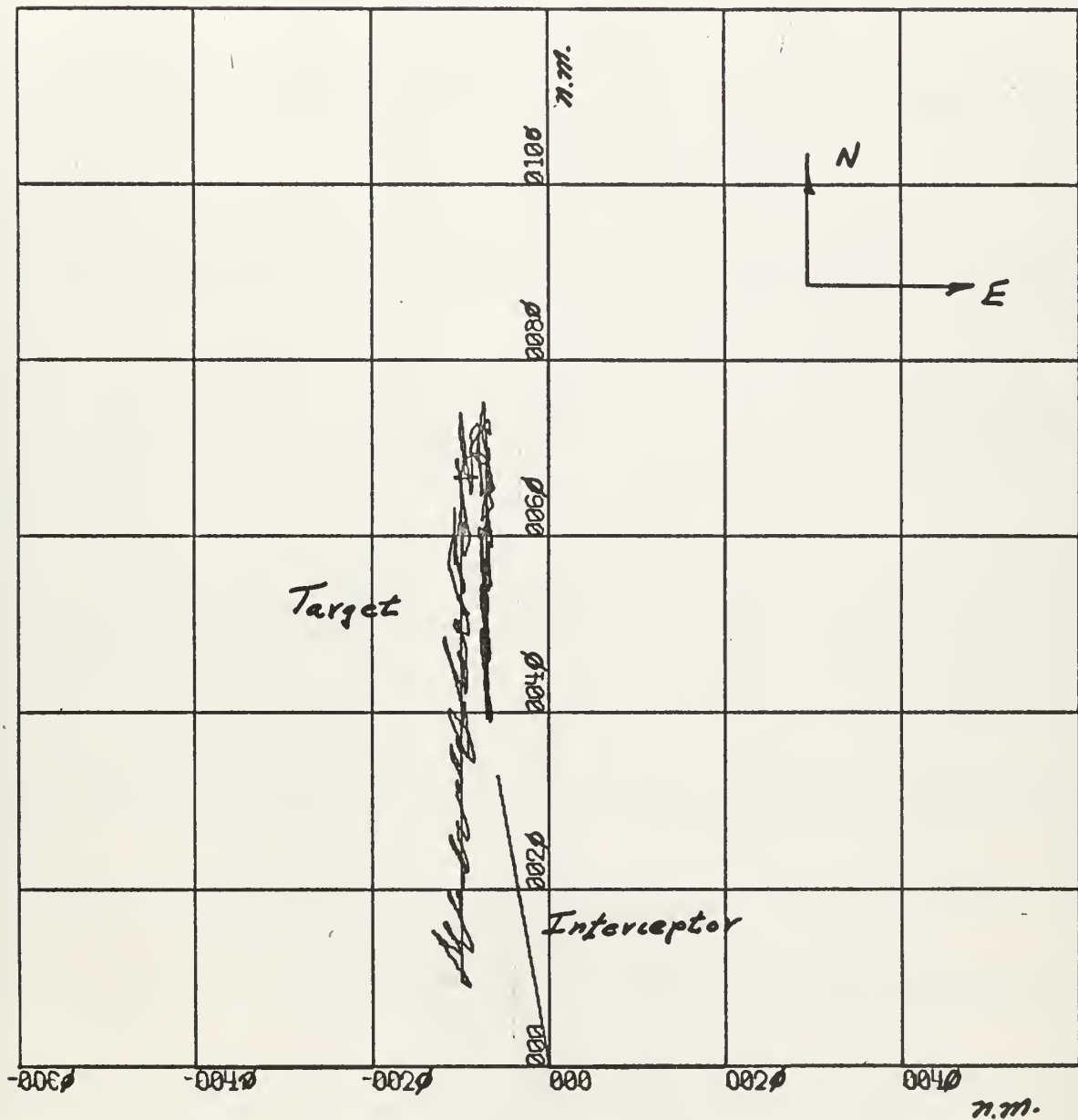
226.	34.0749	2.1787	.6855	1	10
228.	33.3975	.4082	.5342	1	10
230.	32.7206	1.3724	.8840	1	10
232.	32.0440	2.1839	.6753	1	10
234.	31.3678	2.7252	.9610	1	10
236.	30.6924	3.6988	1.1270	1	10
238.	30.0179	.7710	.5272	1	10
240.	29.3435	.7381	.4593	1	10
242.	28.6691	2.6855	1.1992	1	10
244.	27.9965	6.0145	3.3541	1	10
246.	27.3240	.7808	1.7433	1	10
248.	26.6523	3.5173	1.7405	0	9
250.	25.9817	.7993	1.2639	1	10
252.	25.3124	2.2336	.3740	1	10
254.	24.6440	.9793	.3205	1	10
256.	23.9762	3.1969	1.3033	1	10
258.	23.3099	4.0120	1.1218	1	10
260.	22.6455	4.3144	2.5606	1	10
262.	21.9819	2.9578	2.7006	1	10
264.	21.3204	2.5896	2.6388	1	10
266.	20.6607	2.9779	.1962	1	10
268.	20.0023	5.9153	2.7239	1	10
270.	19.3461	1.0316	1.9358	1	10
272.	18.6925	3.2929	.4368	1	10
274.	18.0411	3.2258	1.2219	1	10
276.	17.3924	.1839	.7240	1	10
278.	16.7475	1.0062	.0602	1	10
280.	16.1055	3.8057	1.7427	1	10
282.	15.4672	4.8647	1.2413	1	10
284.	14.8336	.6335	.4280	1	10
286.	14.2050	.9860	.6522	1	10
288.	13.5825	1.6242	.3983	1	10
290.	12.9671	4.7467	2.3462	1	10
292.	12.3584	.9923	1.7011	1	10
294.	11.7589	2.1678	.1597	1	10
296.	11.1693	.8452	.4479	1	10
298.	10.5914	2.4414	.8965	1	10
300.	10.0282	.9809	.9373	0	9

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FIGURE 16



X-SCALE = 2.00E+01 UNITS/INCH

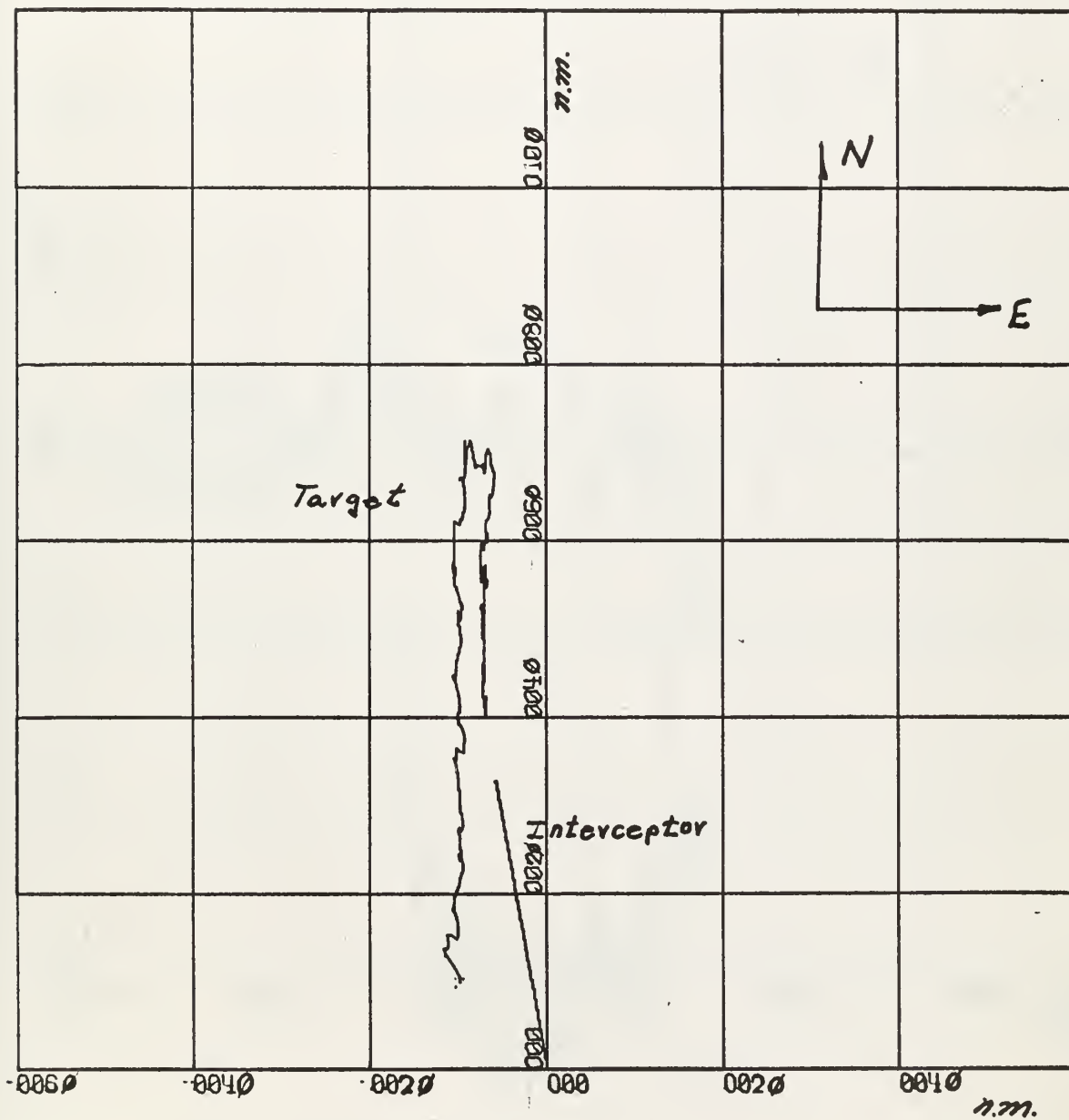
Y-SCALE = 2.00E+01 UNITS/INCH

GENTZ NE FLANE ACTUAL + NOISE RUN 2A

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FIGURE 17



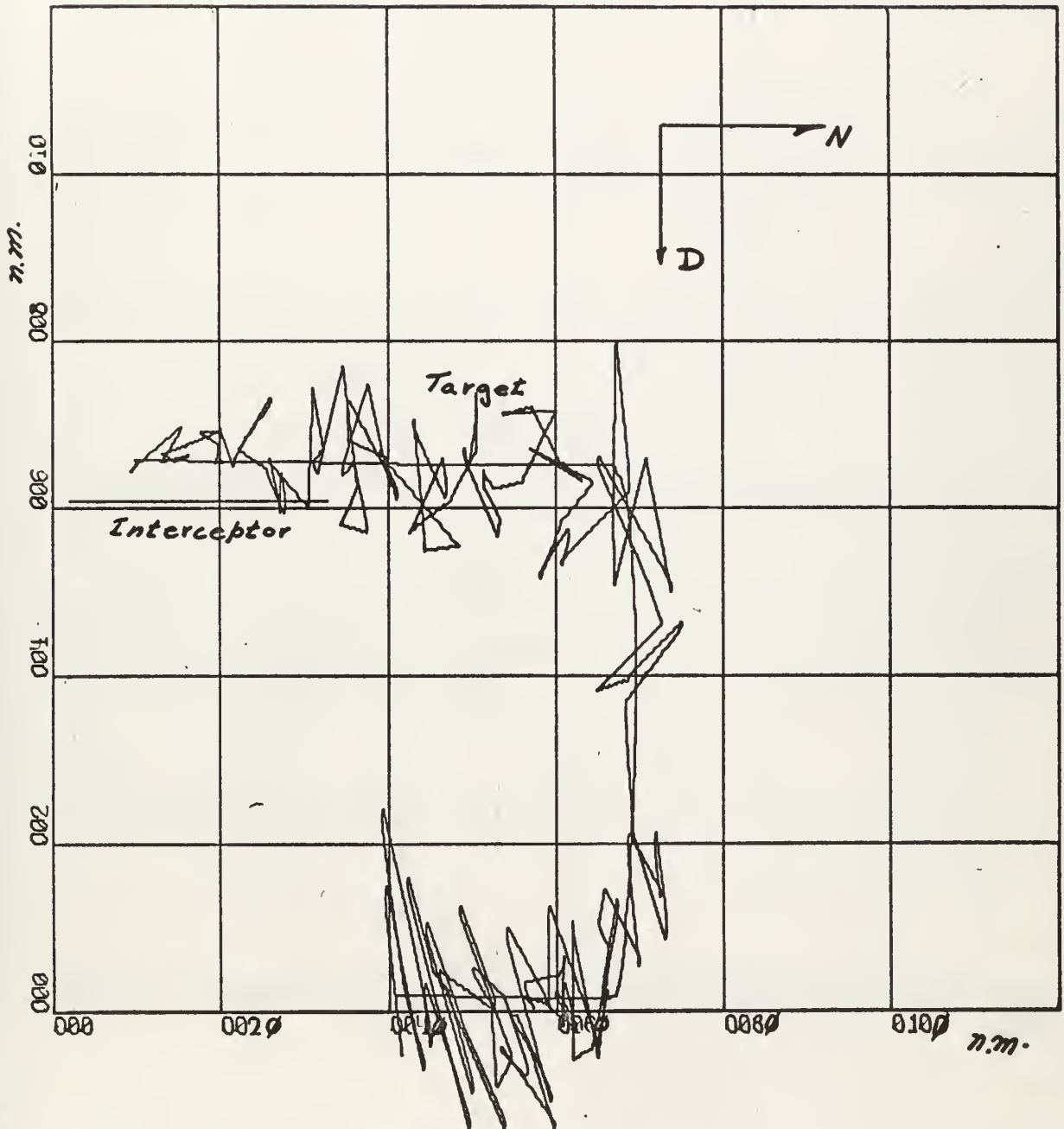
X-SCALE = $2.00E+01$ UNITS/INCH
Y-SCALE = $2.00E+01$ UNITS/INCH

GENTZ NE PLANE SMOOTHED POSITION RUN 2A

00 000 00 000 00 00 00 0 00 00
 00 00 00 00 00 00 00 00 00 00
 00 000 00 00 00 00 00 000 00 00 00

04070216180

FIGURE 18



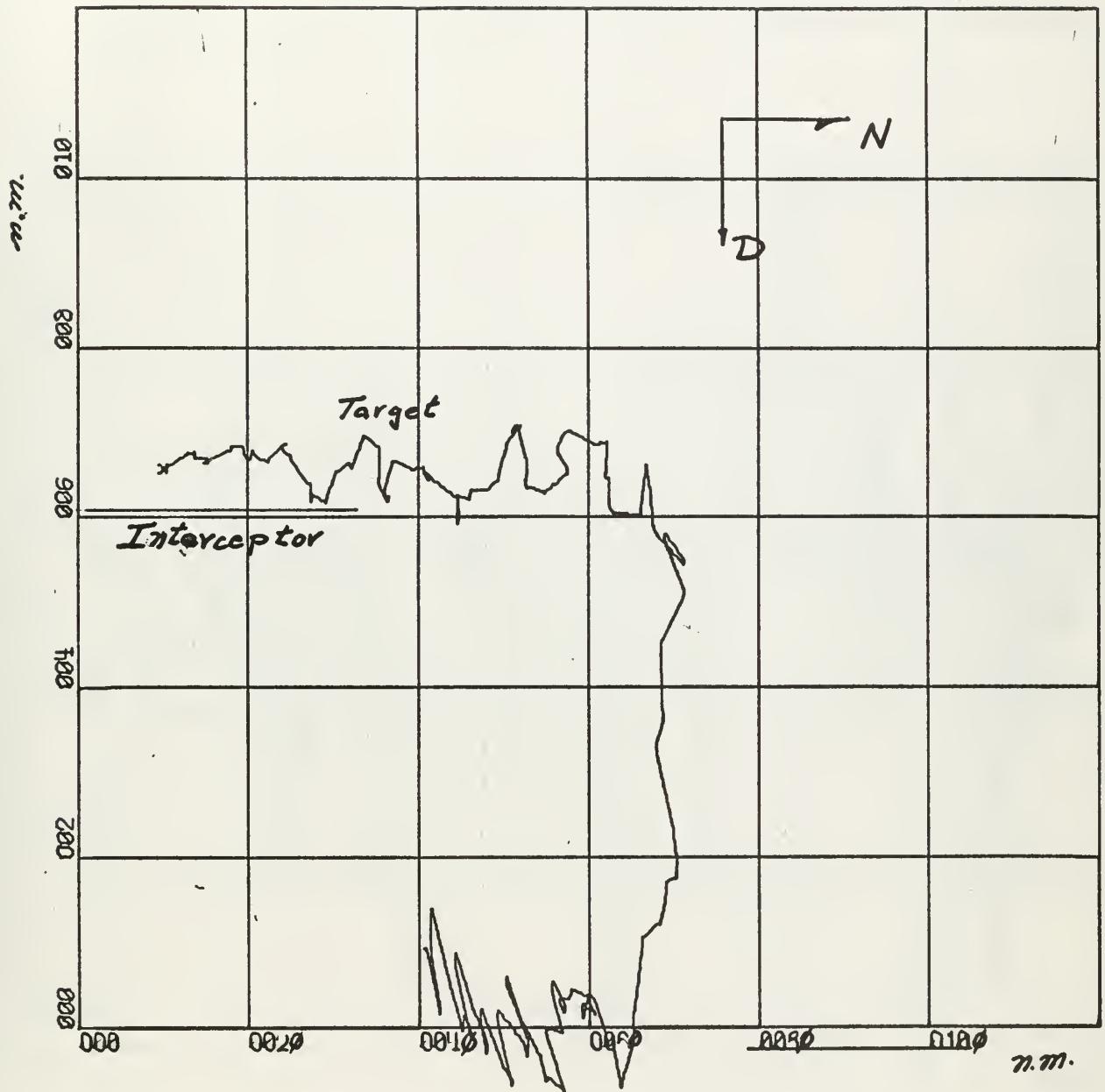
X-SCALE = 2.00E+01 UNITS/INCH

Y-SCALE = 2.00E+00 UNITS/INCH

GENTZ ND PLANE ACTUAL + NOISE

RUN 2A

FIGURE 19



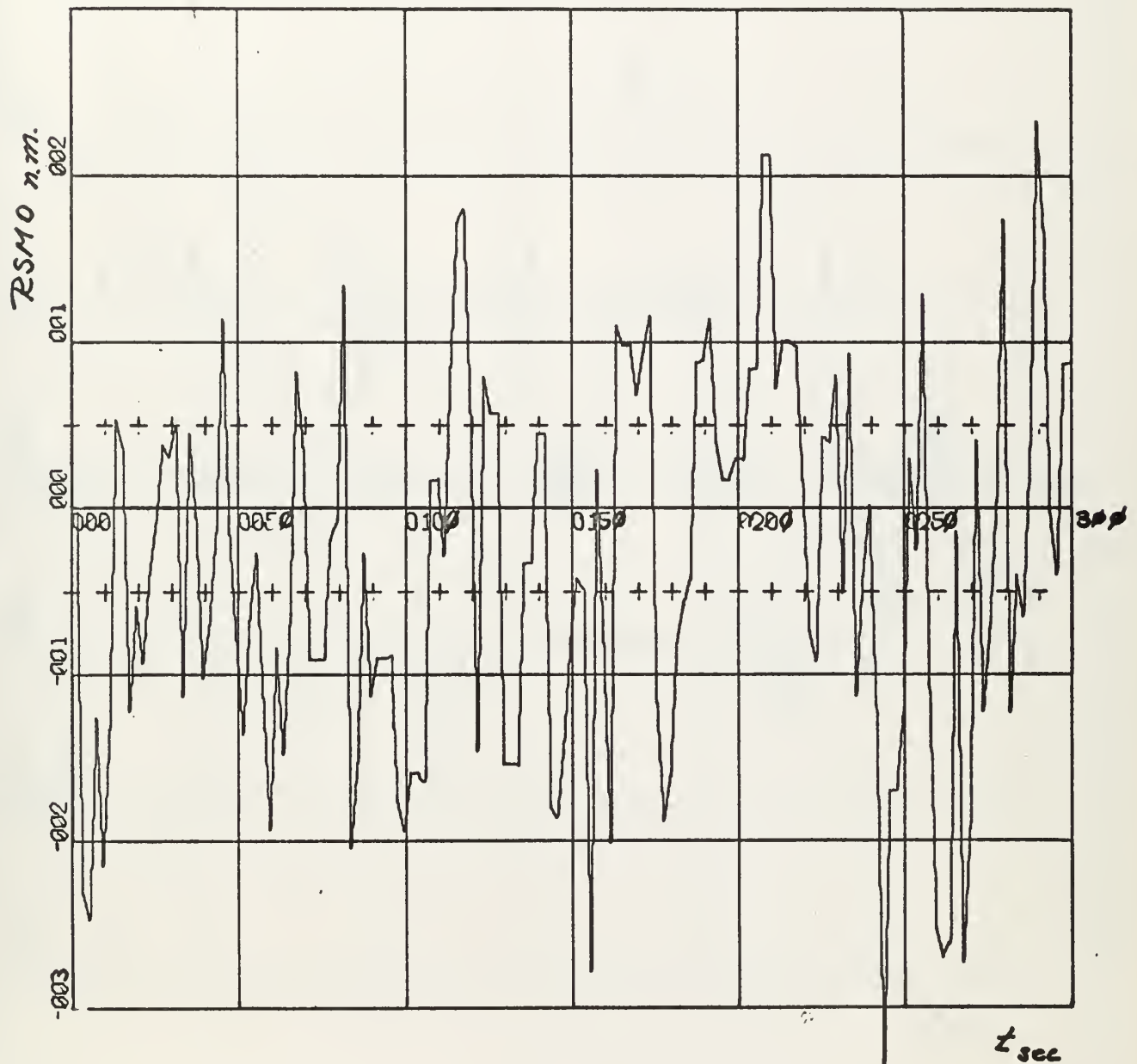
X-SCALE = $2.00E+01$ UNITS/INCH

Y-SCALE = $2.00E+00$ UNITS/INCH

GENTZ ND-PLANE SMOOTHED POSITION RUN 2A

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FIGURE 20



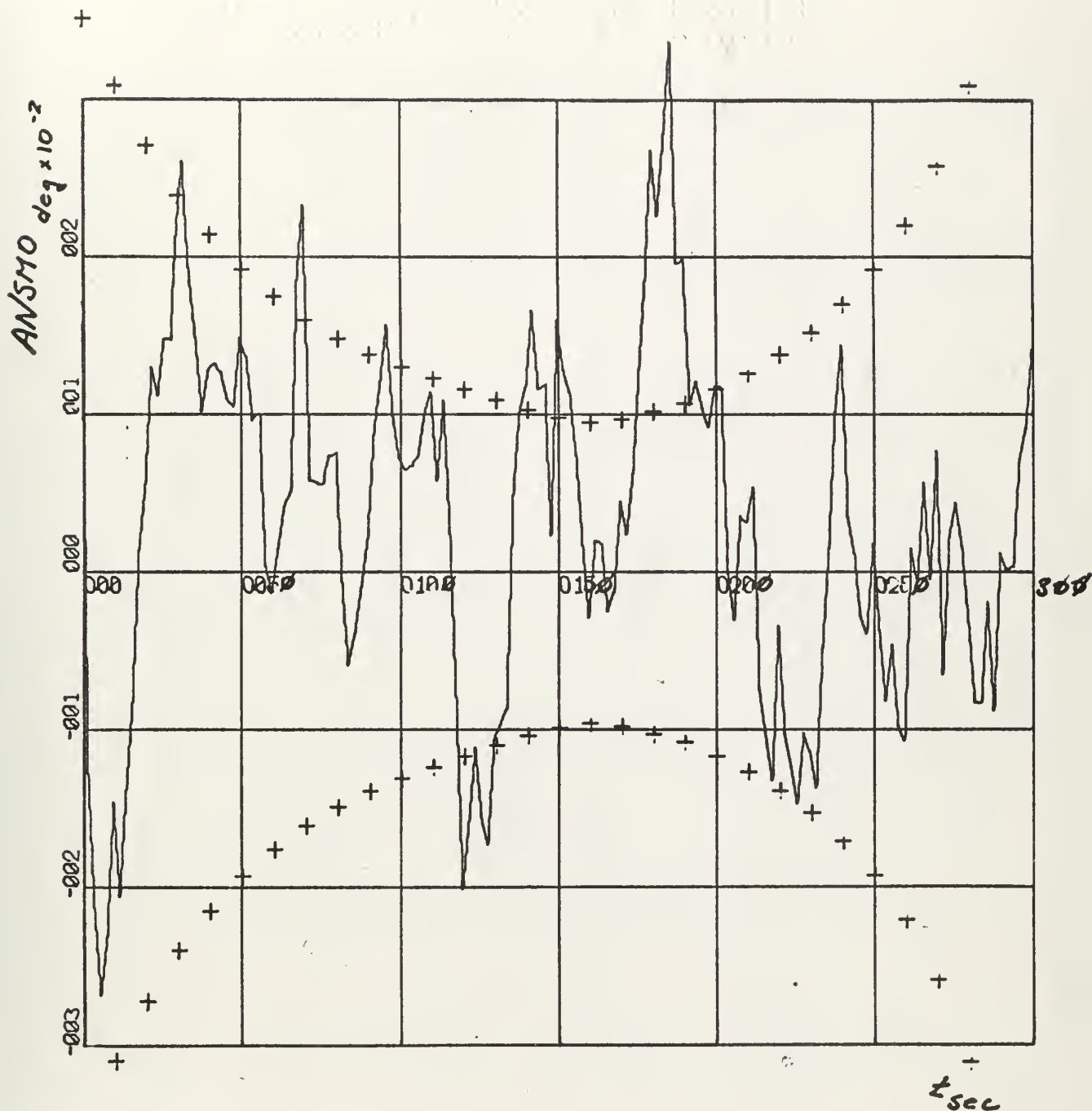
X-SCALE = $5.00E+01$ UNITS/INCH

Y-SCALE = $1.00E+00$ UNITS/INCH

GENTZ RANGE SMOOTHING RESULTS

RUN 2A

FIGURE 21



X-SCALE = 5.00E+01 UNITS/INCH

Y-SCALE = 1.00E+02 UNITS/INCH

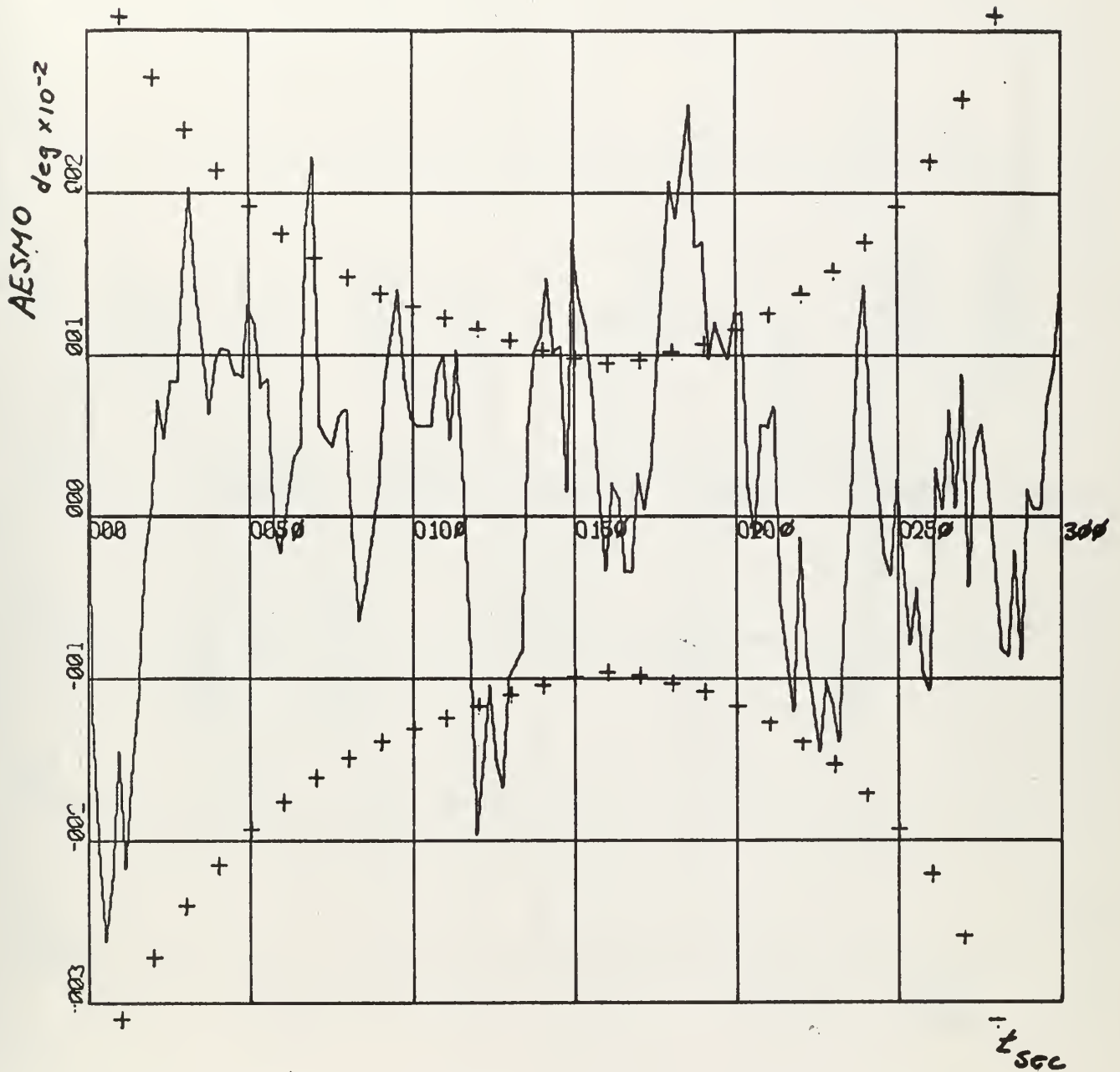
GENTZ-NORTH SMOOTHING RESULTS

RUN 2A

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FIGURE 22



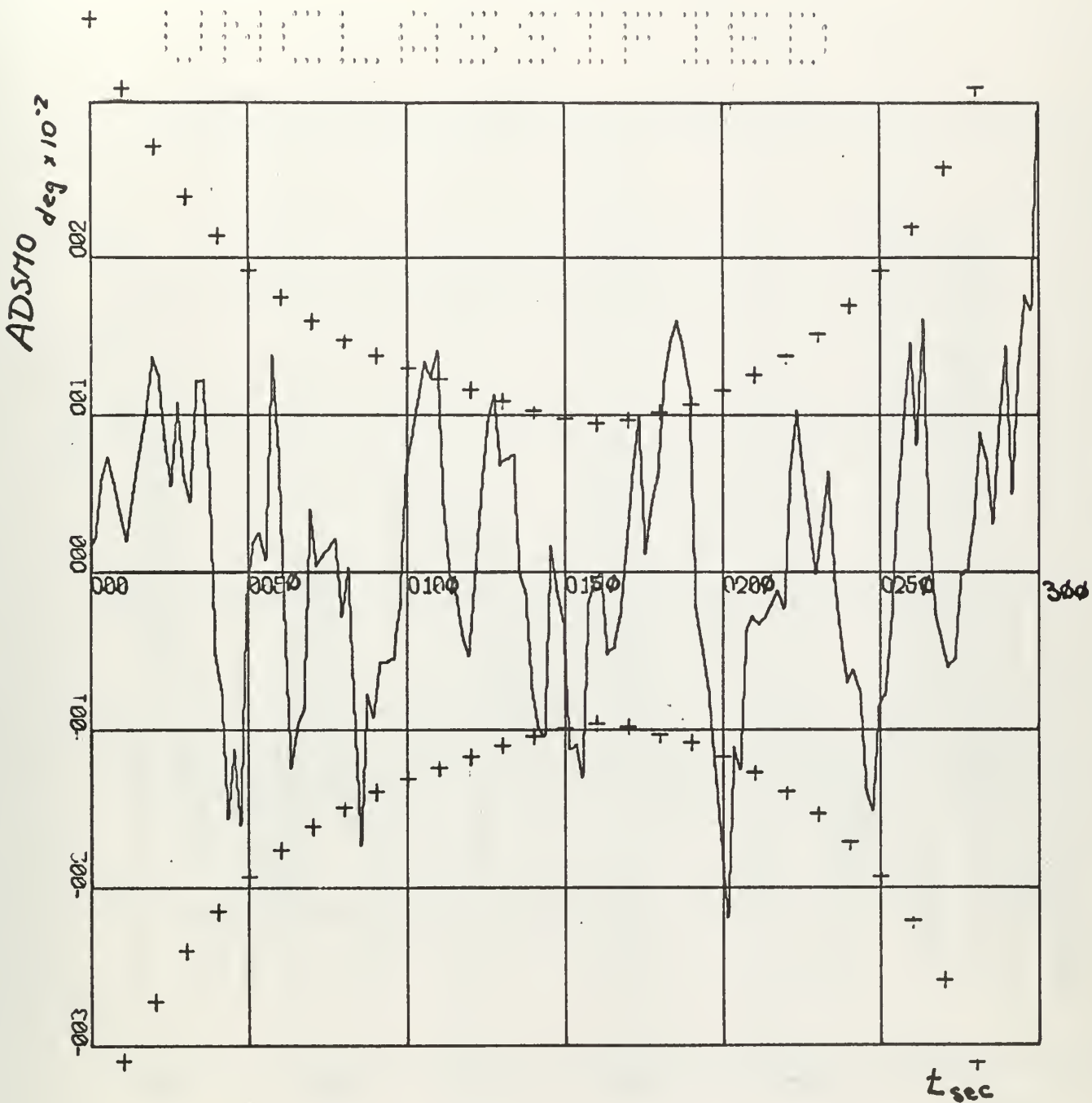
X-SCALE = 5.00E+01 UNITS/INCH

Y-SCALE = 1.00E-02 UNITS/INCH

GENTZ EAST SMOOTHING RESULTS

RUN 2A

FIGURE 23



X-SCALE = 5.00E+01 UNITS/INCH

Y-SCALE = 1.00E-02 UNITS/INCH

GENTZ DOWN SMOOTHING RESULTS

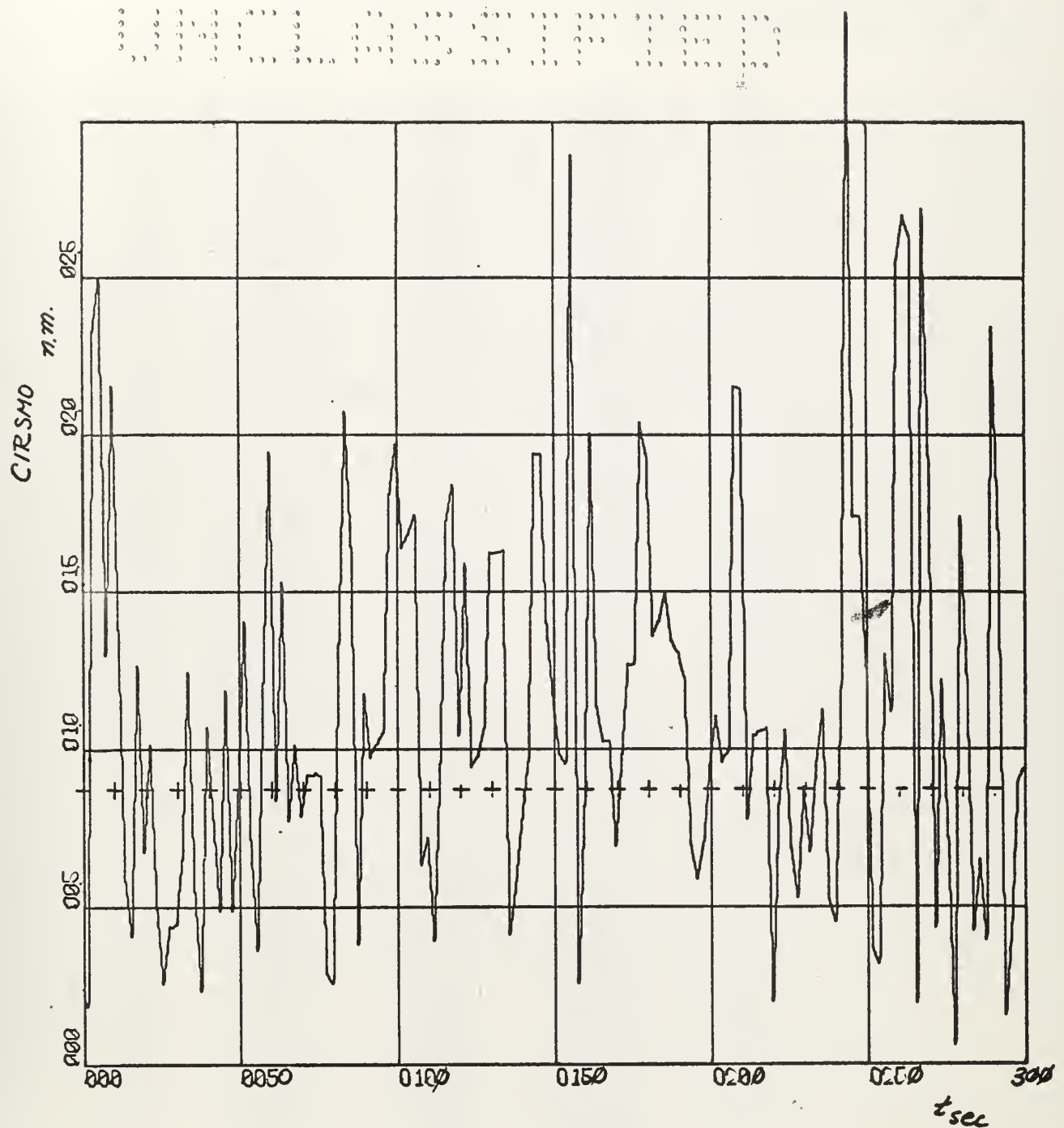
RUN 2A

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[illegible]

FIGURE 24

X-SCALE = $5.00E+01$ UNITS/INCHY-SCALE = $5.00E-01$ UNITS/INCH

GENTZ 3D RMS SMOOTHING RESULTS

RUN 2A

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SMOOTHING RESULTS

RUN 3A

T=TIME, R NM=ACTUAL RANGE, CIRERR=3DIMENSIONAL RMS ACTUAL ERROR,
CIRSMO=3 DIMENSIONAL RMS SMOOTHED ERROR, ND=1 DETECTION, ND=0 NO
DETECTION, NO=QUALITY COUNTER, WHEN NO=0 TARGET CONSIDERED LOST AND
ALL NINES ARE PRINTED.

T	R NM	CIRERR	CIRSMO	ND	NO
.	64.0331	999.9999	999.9999	99	0
2.	63.3432	999.9999	999.9999	99	0
4.	62.6615	5.2284	5.2284	1	2
6.	61.9874	2.7182	4.6090	1	4
8.	61.3185	.2872	5.5982	0	3
10.	60.6536	3.2794	6.6195	0	2
12.	59.9917	1.6075	7.6619	0	1
14.	59.3272	2.8920	3.6603	1	3
16.	58.6651	.7415	4.6221	0	2
18.	58.0138	3.2788	5.5782	0	1
20.	57.3638	999.9999	999.9999	99	0
22.	56.7166	1.5299	1.5299	1	2
24.	56.0745	.3846	2.2500	0	1
26.	55.4404	.5298	1.5796	1	3
28.	54.8201	1.5294	1.0911	1	5
30.	54.2051	1.0748	.8828	1	7
32.	53.5976	1.3123	1.6640	0	6
34.	52.9995	3.4929	2.8562	1	8
36.	52.4058	2.4402	1.1354	1	10
38.	51.8165	.7161	1.2831	1	10
40.	51.2350	2.6550	2.0668	1	10
42.	50.6614	.6466	1.7287	1	10
44.	50.0936	1.4282	2.4901	0	9
46.	49.5372	2.7713	.6522	1	10
48.	48.9957	2.0566	1.2807	0	9
50.	48.4667	2.3367	1.9261	0	8
52.	47.9451	2.1026	2.3270	1	10
54.	47.4298	.1763	1.5481	1	10
56.	46.9230	.5103	1.1057	1	10
58.	46.4283	2.8799	1.9722	1	10
60.	45.9465	2.9172	2.5485	0	9
62.	45.4729	1.2985	3.1176	0	8
64.	45.0096	2.6134	2.9528	1	10
66.	44.5609	.3172	1.7675	1	10
68.	44.1256	3.0541	.5865	1	10
70.	43.7018	1.6328	.9893	1	10
72.	43.2920	2.6931	1.5273	1	10
74.	42.8956	4.2163	1.9088	0	9
76.	42.5102	4.3487	2.2854	0	8
78.	42.1371	.7797	1.1668	1	10
80.	41.7768	.6017	.8212	1	10
82.	41.4294	3.1609	.8167	1	10
84.	41.0970	6.2959	2.5325	1	10
86.	40.7797	1.5041	2.0367	1	10
88.	40.4761	1.4301	.6766	1	10
90.	40.1844	2.2406	1.4451	1	10
92.	39.9054	.8812	1.1853	1	10
94.	39.6402	4.1764	1.3252	0	9
96.	39.3887	.8162	1.4454	0	8
98.	39.1518	2.9079	2.1325	1	10
100.	38.9300	2.2865	2.1741	1	10
102.	38.7226	1.2349	1.7783	1	10

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104.	38.5297	.9965	1.8432	0	9
106.	38.3503	1.3215	1.9278	0	8
108.	38.1848	2.4956	.5250	1	10
110.	38.0346	1.5309	.5820	0	9
112.	37.9008	1.1135	.4883	1	10
114.	37.7849	2.3822	.7989	1	10
116.	37.6863	2.8018	1.6387	1	10
118.	37.6061	2.0459	1.7803	1	10
120.	37.5459	1.4986	.9739	1	10
122.	37.5045	3.9605	1.6202	1	10
124.	37.4788	3.5794	.9011	1	10
126.	37.4685	1.0004	.8735	1	10
128.	37.4751	2.5266	.9217	0	9
130.	37.4993	4.0935	1.6939	1	10
132.	37.5383	3.1103	1.7536	0	9
134.	37.5921	3.7243	1.8317	0	8
136.	37.6634	1.5543	.5339	1	10
138.	37.7527	4.4405	.6837	0	9
140.	37.8630	1.5008	.5356	1	10
142.	37.9903	3.3820	1.6679	1	10
144.	38.1305	4.5163	1.3734	1	10
146.	38.2891	2.2521	1.6145	1	10
148.	38.4717	1.0184	1.2851	1	10
150.	38.6742	1.5588	.9766	1	10
152.	38.8196	1.0862	.8368	1	10
154.	38.8491	3.1644	.8925	0	9
156.	38.7656	5.5166	2.8681	1	10
158.	38.5776	4.1332	.4266	1	10
160.	38.3053	1.8729	.7371	1	10

162.	37.9787	3.3661	1.9108	1	10
164.	37.6361	5.1068	1.3710	1	10
166.	37.3107	1.0431	1.2419	1	10
168.	36.9799	5.6588	1.4940	0	9
170.	36.6259	.4481	1.1520	1	10
172.	36.2803	1.1135	1.2744	1	10
174.	35.9586	1.5451	1.6284	0	9
176.	35.6751	4.5126	1.2923	1	10
178.	35.4273	3.1534	2.0551	1	10
180.	35.1865	4.2473	1.9926	0	9
182.	34.9512	.7718	1.3195	1	10
184.	34.6887	2.1744	1.3184	0	9
186.	34.3714	2.3991	1.2573	1	10
188.	34.0072	2.4130	1.6659	1	10
190.	33.6073	.6771	1.6882	0	9
192.	33.1834	1.6046	1.5719	1	10
194.	32.7565	.7703	.8252	1	10
196.	32.3302	.3318	.6356	1	10
198.	31.9053	2.6663	.7830	0	9
200.	31.4831	.8586	.9181	1	10
202.	31.0616	2.0547	1.2914	1	10
204.	30.6429	1.6486	1.3221	1	10
206.	30.2249	2.2947	1.3599	0	9
208.	29.8092	3.7582	2.3422	1	10
210.	29.3963	3.1228	2.6788	1	10
212.	28.9854	1.0196	1.0493	1	10
214.	28.5769	1.4864	1.2071	1	10
216.	28.1695	1.2797	.1447	1	10
218.	27.7643	.5272	.1242	0	9
220.	27.3634	.9118	.4105	1	10
222.	26.9647	2.0230	1.0156	1	10
224.	26.5680	1.2445	1.1168	1	10

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TABLE VII

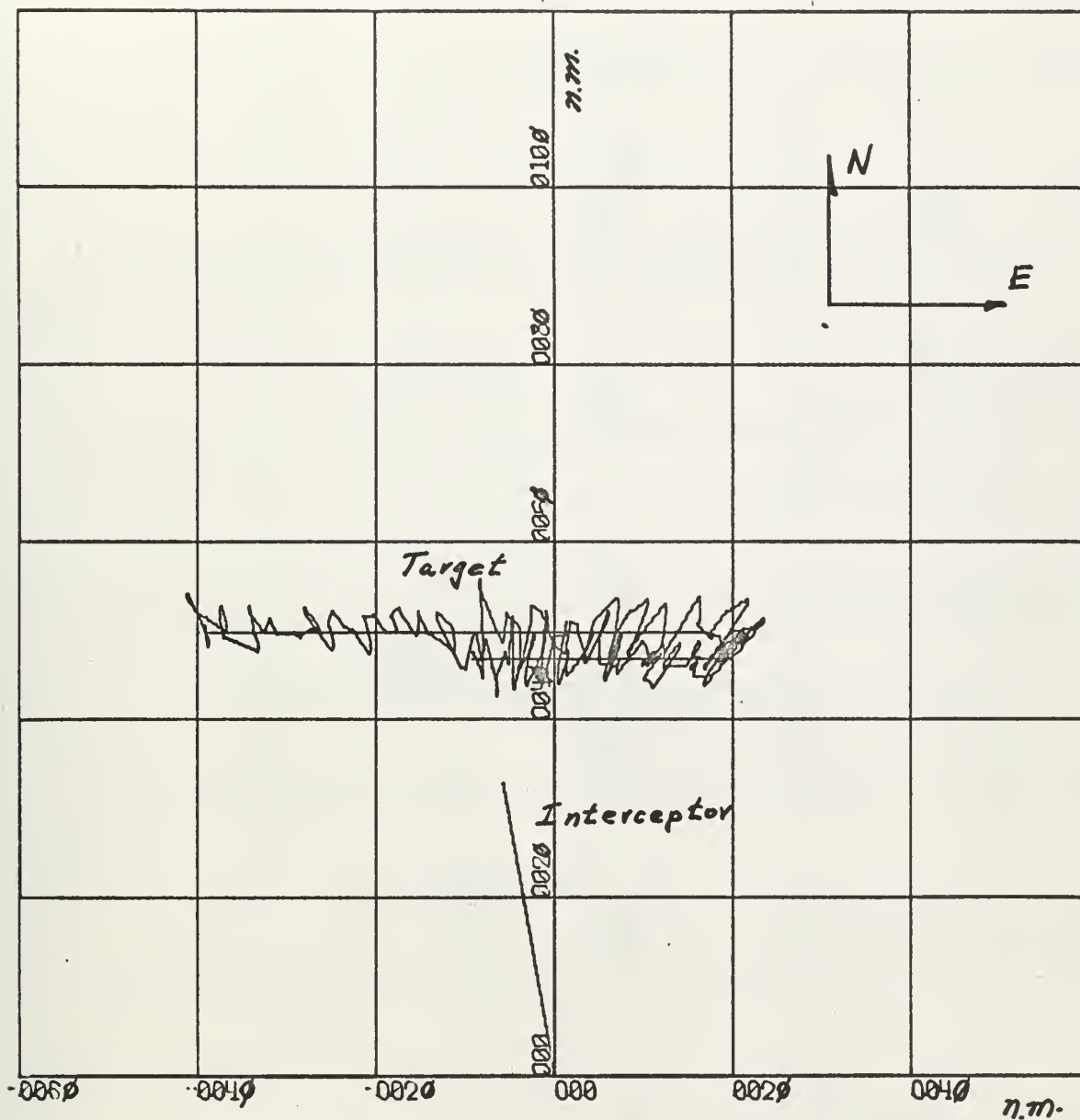
226.	26.1748	2.1479	.4756	1	10
228.	25.7845	.3876	.4112	1	10
230.	25.3963	1.3388	.8952	1	10
232.	25.0123	2.1512	.6203	1	10
234.	24.6304	2.7101	.9254	1	10
236.	24.2535	3.6820	1.1451	1	10
238.	23.8804	.6717	.5093	1	10
240.	23.5097	.6755	.3905	1	10
242.	23.1429	2.6744	1.2051	1	10
244.	22.7823	6.0123	3.3630	1	10
246.	22.4258	.6651	1.7443	1	10
248.	22.0740	3.5154	1.7565	0	9
250.	21.7261	.7764	1.2941	1	10
252.	21.3833	2.2259	.3464	1	10
254.	21.0473	.9641	.3039	1	10
256.	20.7154	3.1924	1.2741	1	10
258.	20.3910	4.0046	1.1196	1	10
260.	20.0734	4.3098	2.5728	1	10
262.	19.7619	2.9459	2.7294	1	10
264.	19.4577	2.5792	2.6587	1	10
266.	19.1605	2.9675	.2325	1	10
268.	18.8707	5.9137	2.7529	1	10
270.	18.5874	1.0253	1.9724	1	10
272.	18.3143	3.2915	.4318	1	10
274.	18.0479	3.2258	1.2655	1	10
276.	17.7910	.1867	.7666	1	10
278.	17.5437	1.0069	.1274	1	10
280.	17.3071	3.8062	1.7151	1	10
282.	17.0794	4.8666	1.2698	1	10
284.	16.8624	.6385	.4451	1	10
286.	16.6565	.9990	.7002	1	10
288.	16.4640	1.6364	.3428	1	10
290.	16.2820	4.7497	2.3317	1	10
292.	16.1119	1.0382	1.7219	1	10
294.	15.9560	2.1743	.0442	1	10
296.	15.8117	.8606	.3557	1	10
298.	15.6809	2.4438	.9915	1	10
300.	15.5659	1.0195	1.1565	0	9

0319128A.J040

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FIGURE 25

X-SCALE = $2.00E+01$ UNITS/INCHY-SCALE = $2.00E+01$ UNITS/INCH

GENTZ NE PLANE ACTUAL + NOISE RUN 3A

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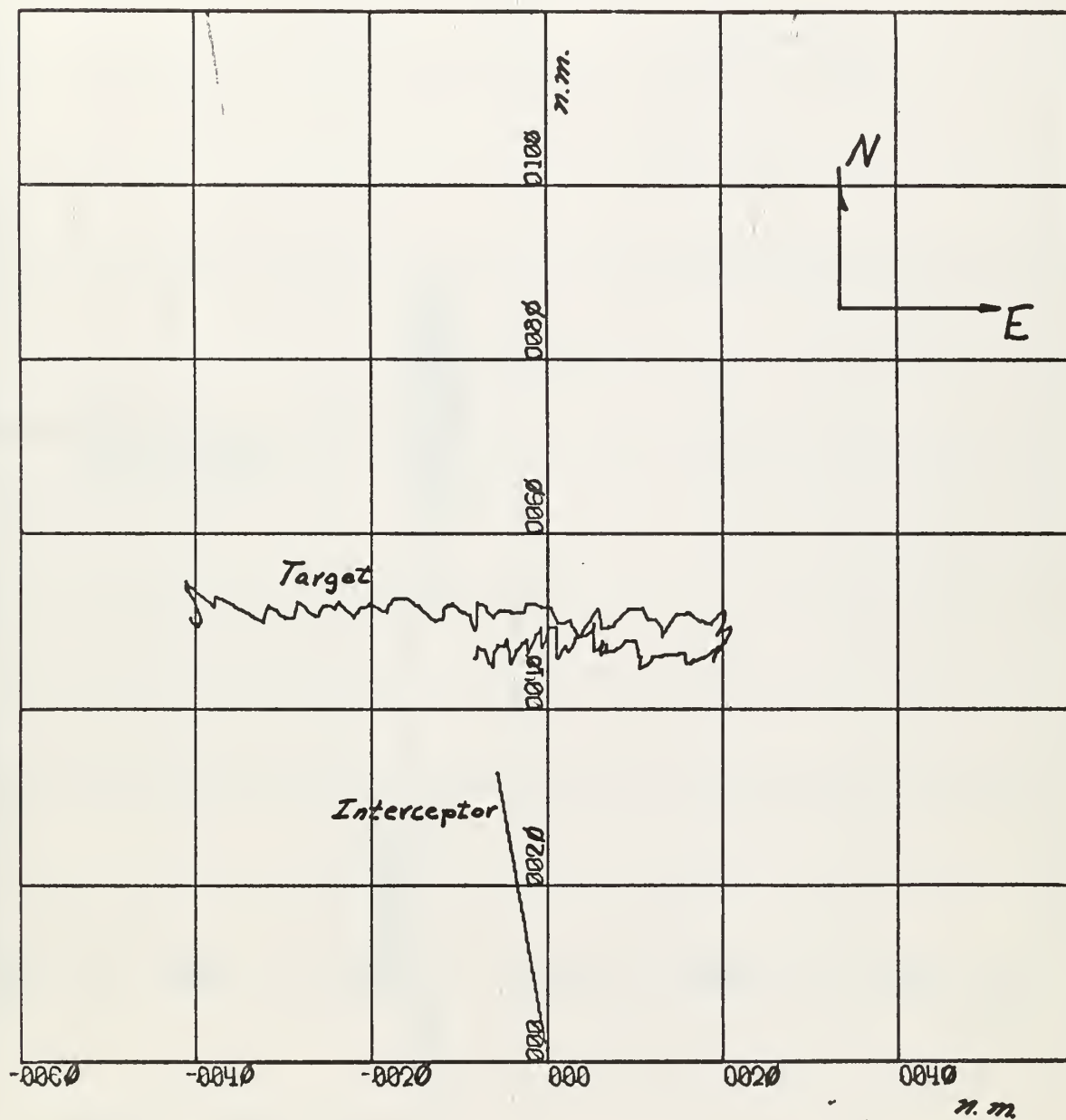


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FIGURE 26



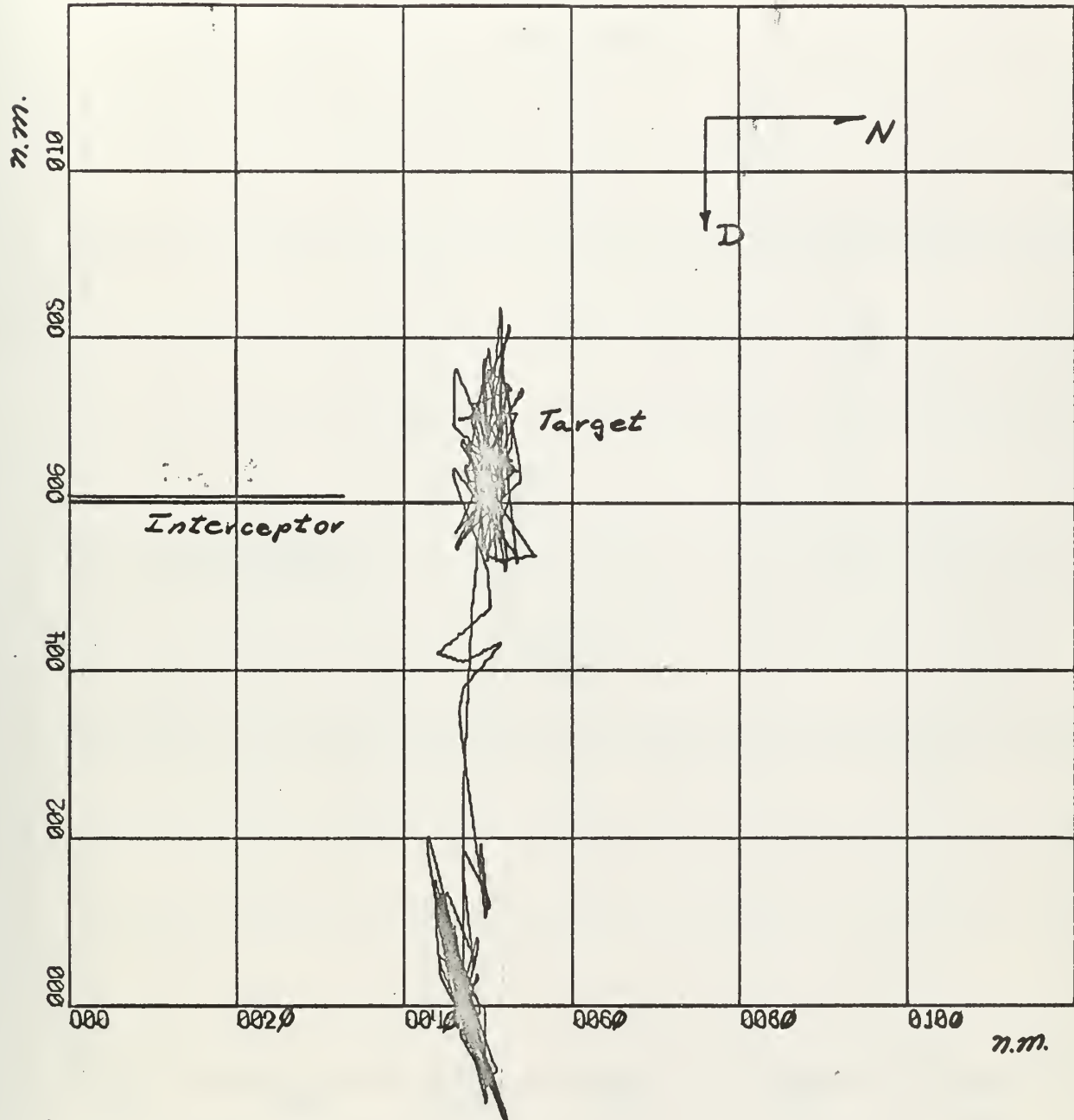
X-SCALE = 2.00E+01 UNITS/INCH

Y-SCALE = 2.00E+01 UNITS/INCH

GENTZ NE PLANE SMOOTHED POSITION RUN 3A

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FIGURE 27



X-SCALE = 2.00E+01 UNITS/INCH
 Y-SCALE = 2.00E+00 UNITS/INCH

GENTZ ND PLANE ACTUAL + NOISE RUN 3A

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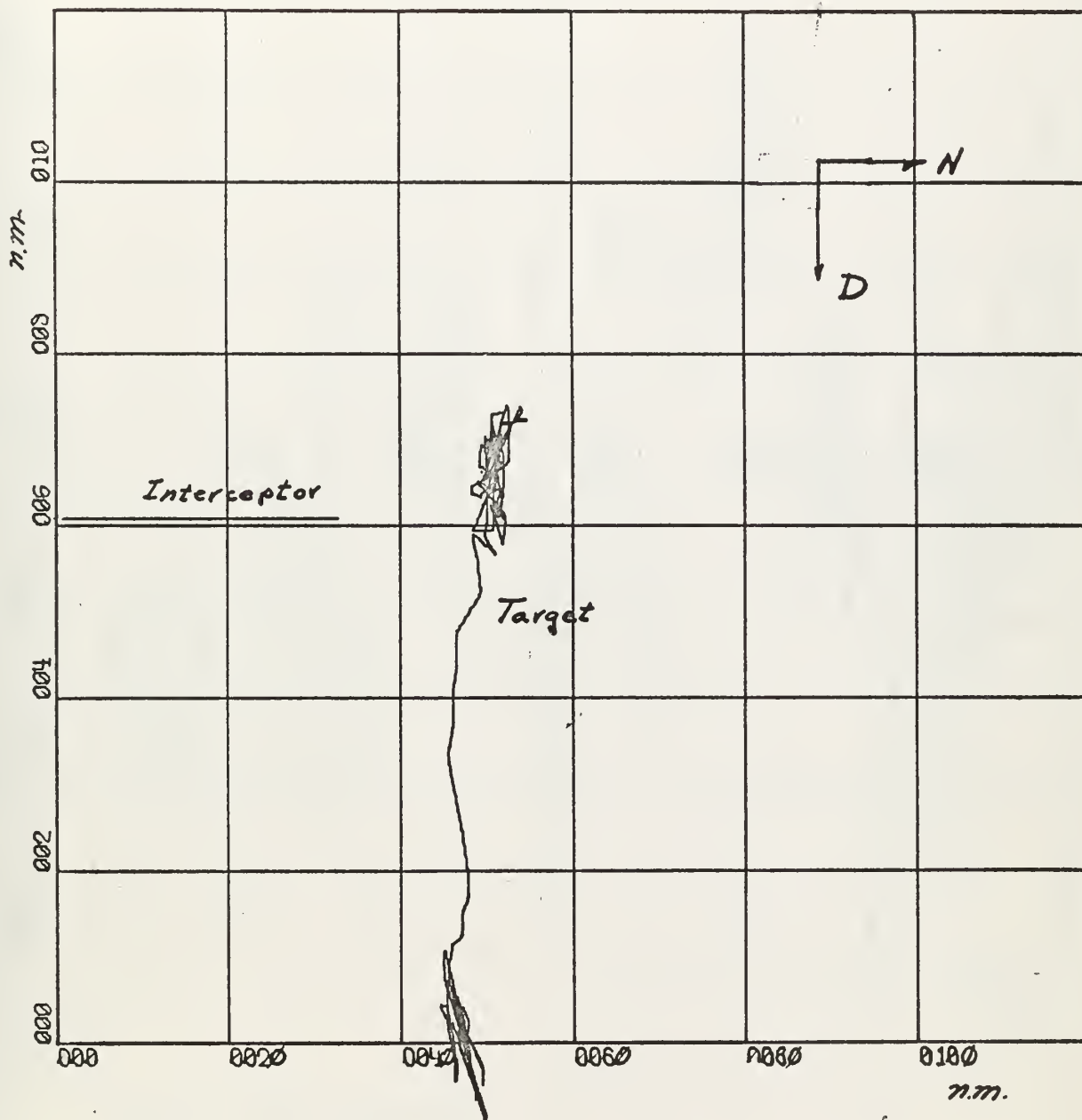
03171234.0400

040703212100

~~CONFIDENTIAL~~

UNCLASSIFIED

FIGURE 28



X-SCALE = 2.00E+01 UNITS/INCH

Y-SCALE = 2.00E+00 UNITS/INCH

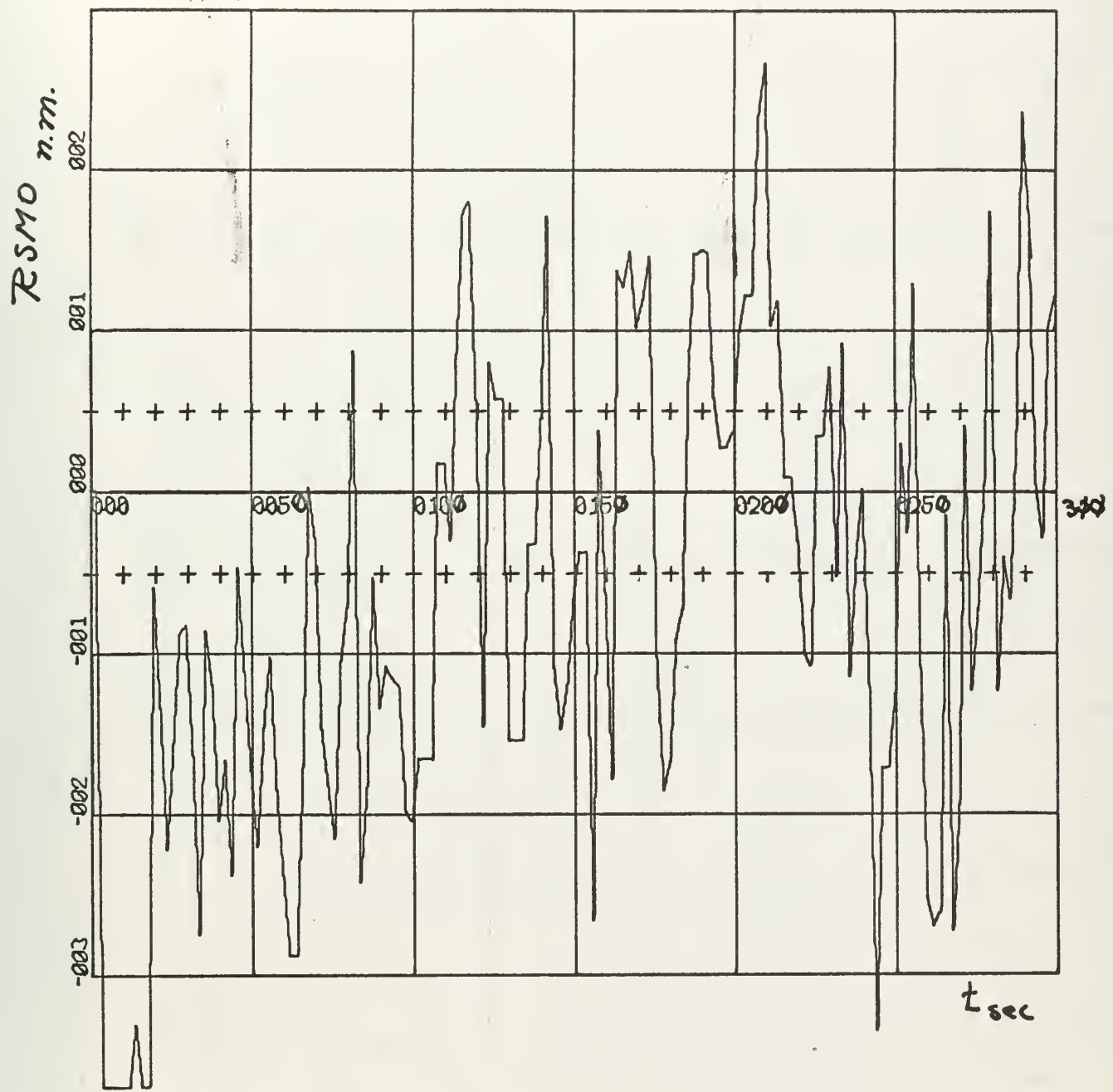
GENTZ NO PLANE SMOOTHED POSITION RUN 3A

~~CONFIDENTIAL~~

0317123A.DRU

NOT OBSERVED

FIGURE 39



X-SCALE = 5.00E+01 UNITS/INCH

Y-SCALE = 1.00E+00 UNITS/INCH

GENTZ RANGE SMOOTHING RESULTS

RUN 3A

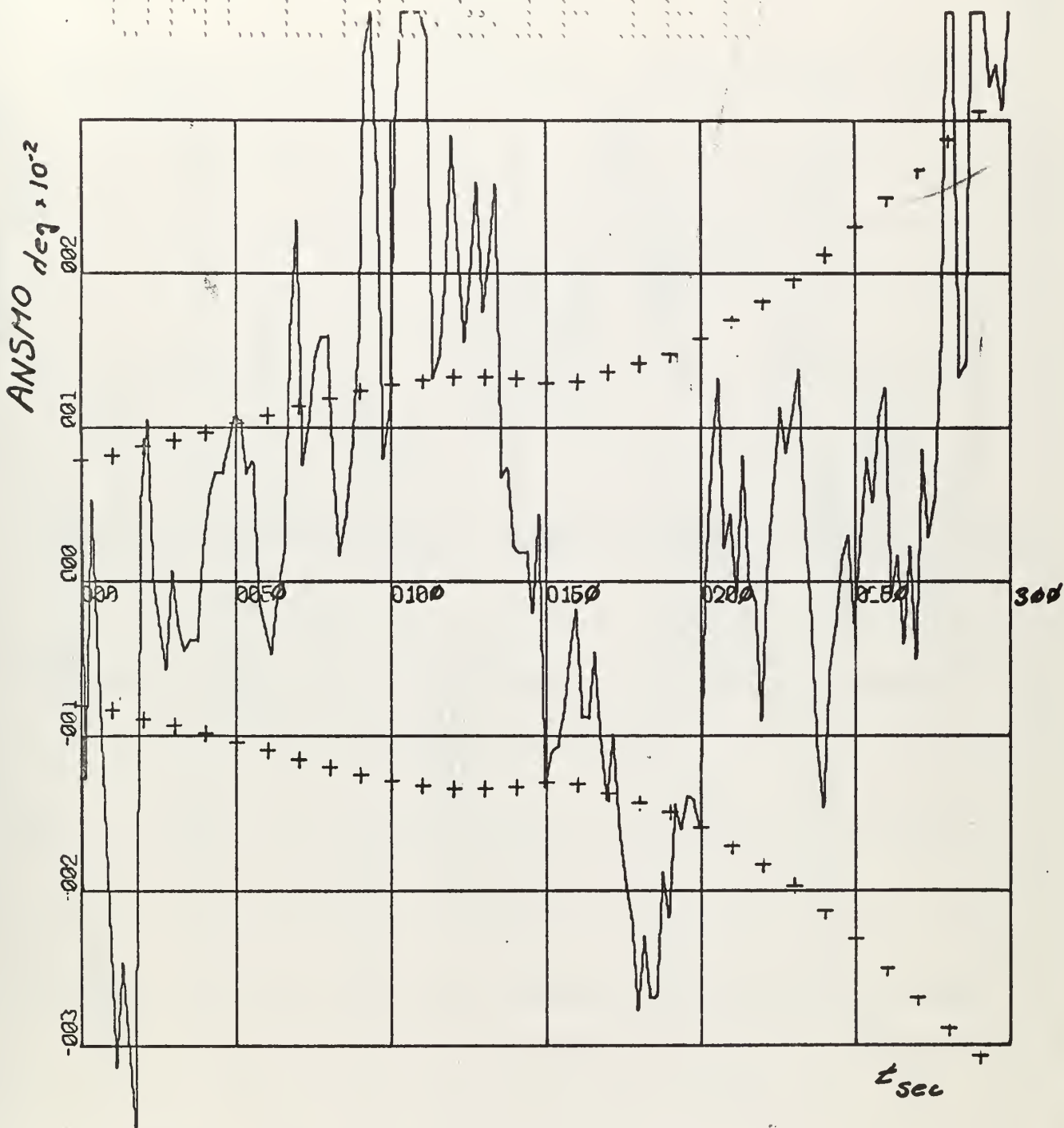
96 of 100

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040703211ED

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FIGURE 30



X-SCALE = $5.00E+01$ UNITS/INCH

Y-SCALE = $1.00E-02$ UNITS/INCH

GENTZ NORTH SMOOTHING RESULTS

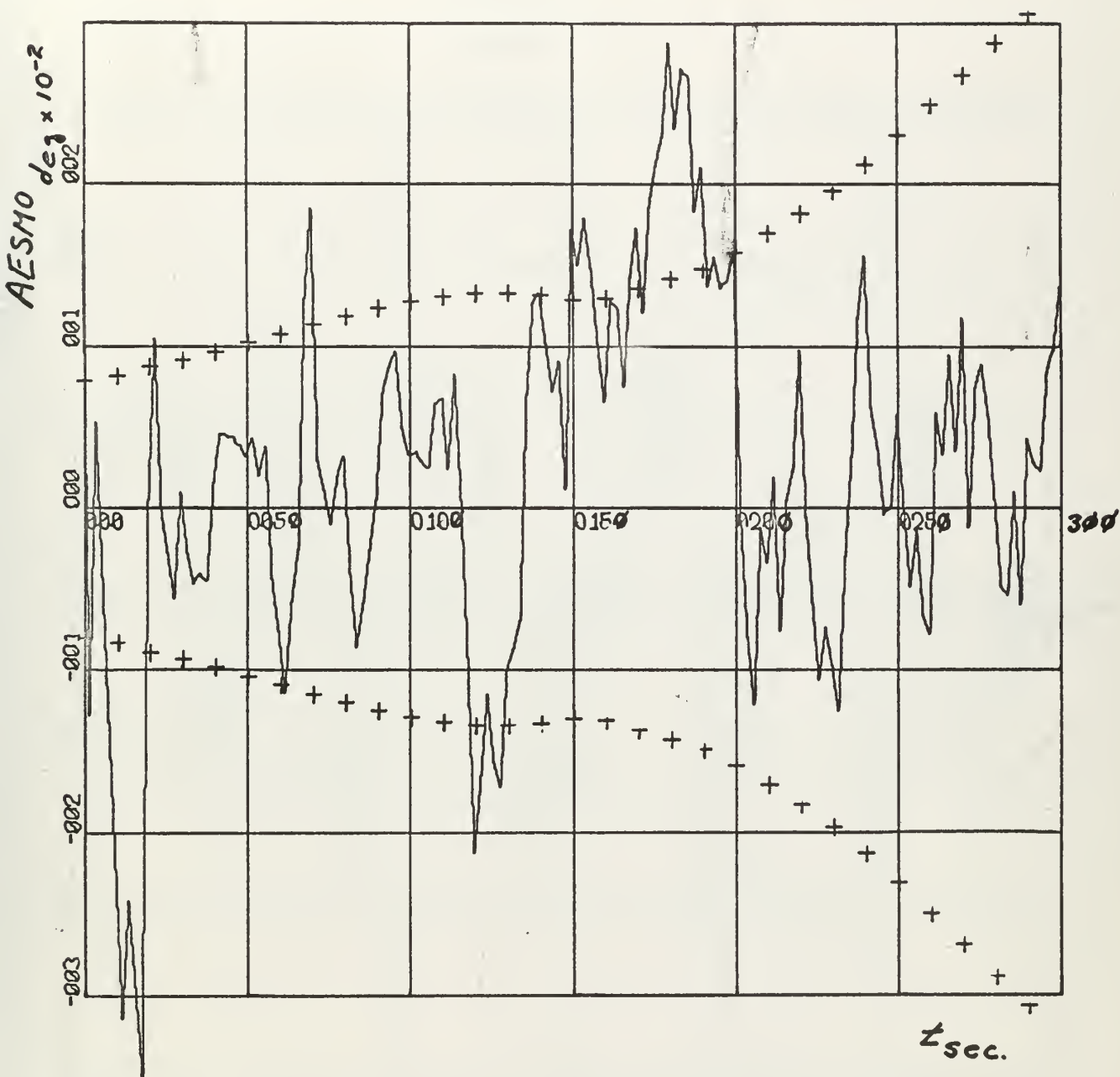
RUN 3A

~~CONFIDENTIAL~~

0314132A.DRU

NRCT 032161ED

FIGURE 31



X-SCALE = $5.00E+01$ UNITS/INCH

Y-SCALE = $1.00E-02$ UNITS/INCH

GENTZ EAST SMOOTHING RESULTS

RUN 3A

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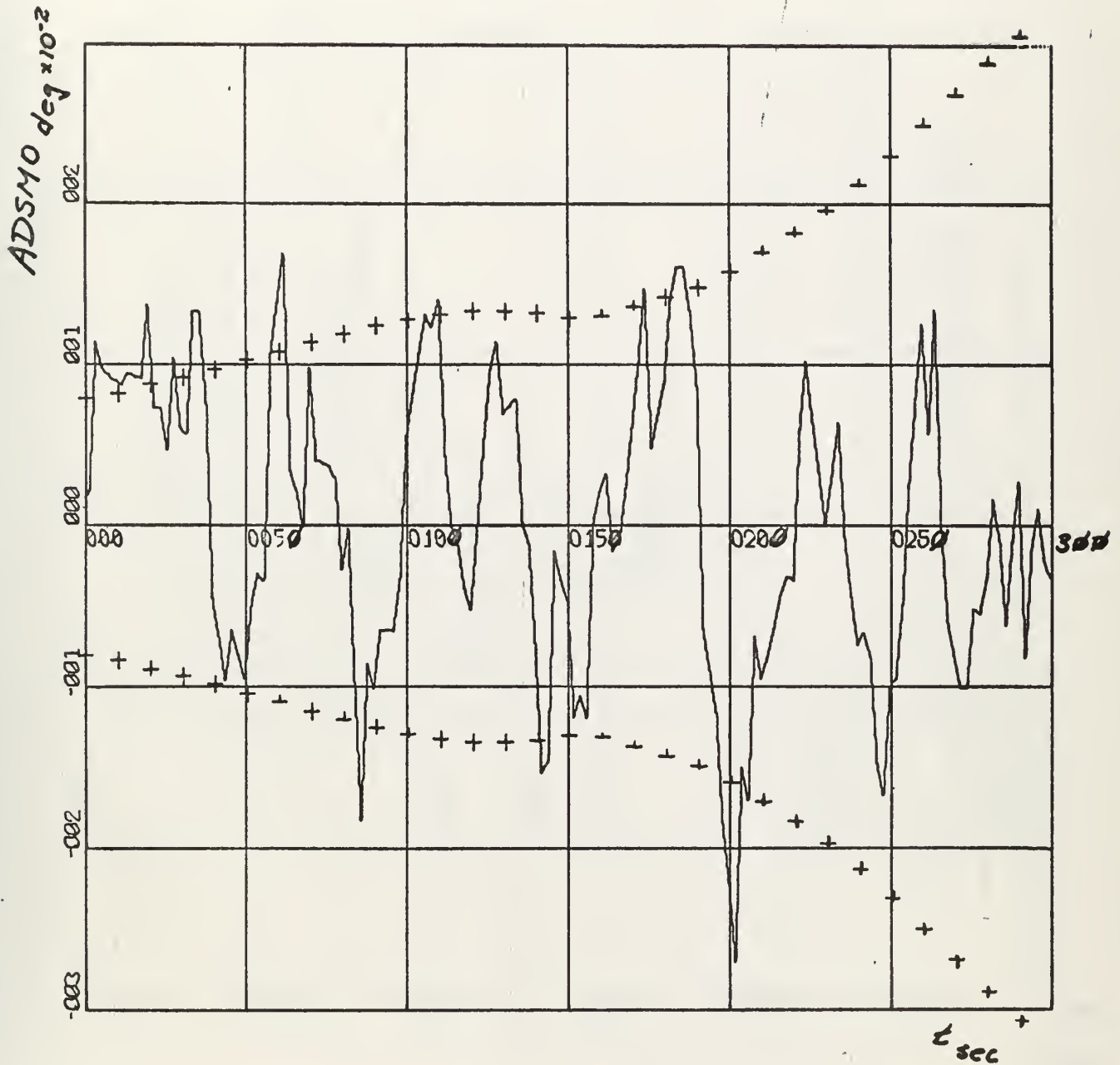
DEFINITION

1. A definition is a statement that explains the meaning of a word or phrase.	
2. It is used to clarify the meaning of a term and to ensure that everyone is talking about the same thing.	
3. Definitions are often used in legal, scientific, and technical contexts.	
4. They can be used to define a word in a specific context or to define a word in general.	
5. Definitions can be used to define a word in a way that is consistent with its use in a particular field.	
6. They can also be used to define a word in a way that is consistent with its use in a particular culture or society.	
7. Definitions are often used to define a word in a way that is consistent with its use in a particular language.	
8. They can also be used to define a word in a way that is consistent with its use in a particular dialect.	
9. Definitions are often used to define a word in a way that is consistent with its use in a particular context.	
10. They can also be used to define a word in a way that is consistent with its use in a particular situation.	
11. Definitions are often used to define a word in a way that is consistent with its use in a particular field of study.	
12. They can also be used to define a word in a way that is consistent with its use in a particular discipline.	
13. Definitions are often used to define a word in a way that is consistent with its use in a particular profession.	
14. They can also be used to define a word in a way that is consistent with its use in a particular industry.	
15. Definitions are often used to define a word in a way that is consistent with its use in a particular community.	
16. They can also be used to define a word in a way that is consistent with its use in a particular group of people.	
17. Definitions are often used to define a word in a way that is consistent with its use in a particular culture.	
18. They can also be used to define a word in a way that is consistent with its use in a particular society.	
19. Definitions are often used to define a word in a way that is consistent with its use in a particular language.	
20. They can also be used to define a word in a way that is consistent with its use in a particular dialect.	

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FIGURE 32



X-SCALE = $5.00E+01$ UNITS/INCH

Y-SCALE = $1.0E-02$ UNITS/INCH

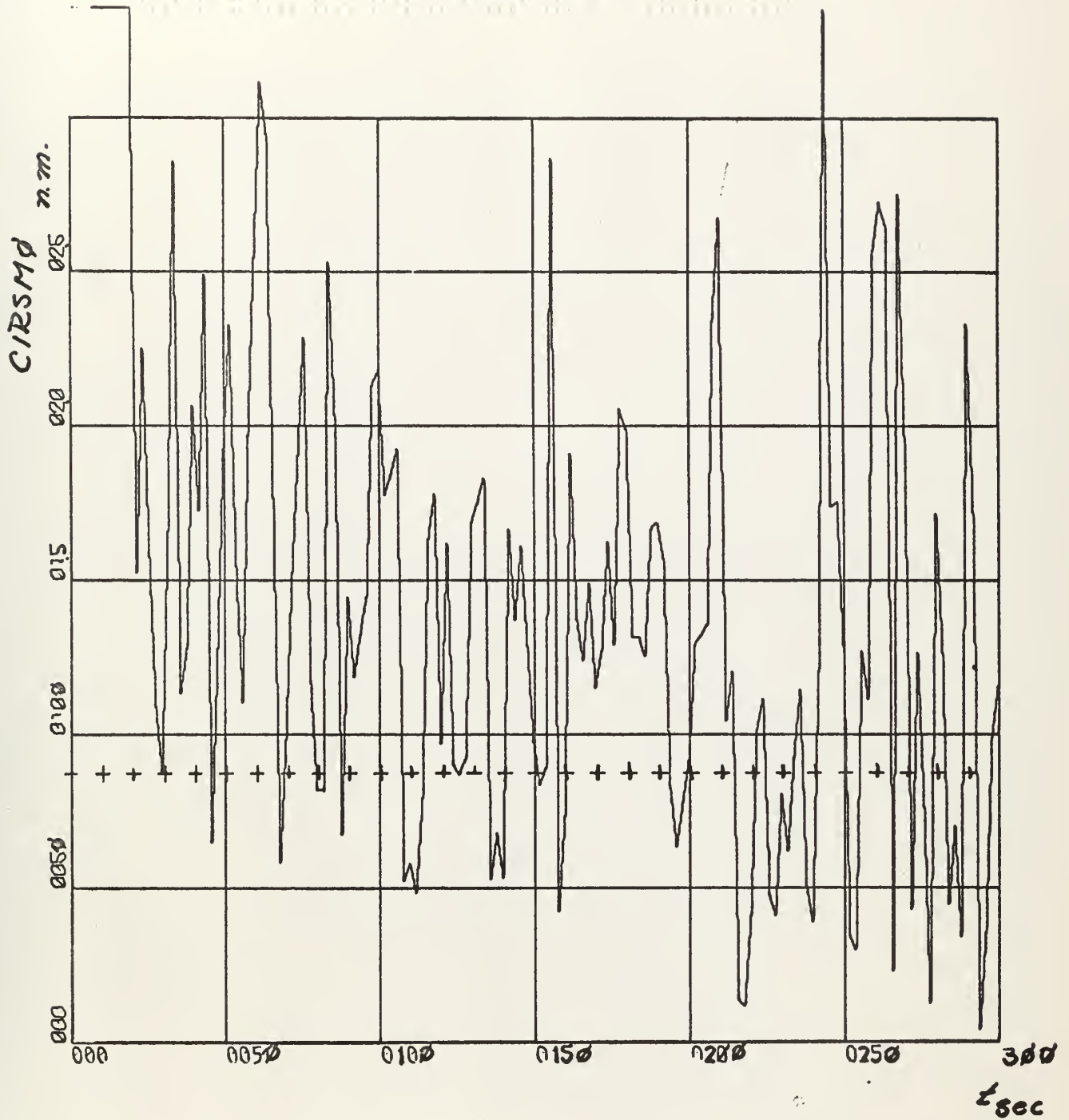
GENTZ DOWN SMOOTHING RESULTS

RUN 3A

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(1) $\{1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212, 213, 214, 215, 216, 217, 218, 219, 220, 221, 222, 223, 224, 225, 226, 227, 228, 229, 230, 231, 232, 233, 234, 235, 236, 237, 238, 239, 240, 241, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 261, 262, 263, 264, 265, 266, 267, 268, 269, 270, 271, 272, 273, 274, 275, 276, 277, 278, 279, 280, 281, 282, 283, 284, 285, 286, 287, 288, 289, 290, 291, 292, 293, 294, 295, 296, 297, 298, 299, 300, 301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314, 315, 316, 317, 318, 319, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 330, 331, 332, 333, 334, 335, 336, 337, 338, 339, 340, 341, 342, 343, 344, 345, 346, 347, 348, 349, 350, 351, 352, 353, 354, 355, 356, 357, 358, 359, 360, 361, 362, 363, 364, 365, 366, 367, 368, 369, 370, 371, 372, 373, 374, 375, 376, 377, 378, 379, 380, 381, 382, 383, 384, 385, 386, 387, 388, 389, 390, 391, 392, 393, 394, 395, 396, 397, 398, 399, 400, 401, 402, 403, 404, 405, 406, 407, 408, 409, 410, 411, 412, 413, 414, 415, 416, 417, 418, 419, 420, 421, 422, 423, 424, 425, 426, 427, 428, 429, 430, 431, 432, 433, 434, 435, 436, 437, 438, 439, 440, 441, 442, 443, 444, 445, 446, 447, 448, 449, 450, 451, 452, 453, 454, 455, 456, 457, 458, 459, 460, 461, 462, 463, 464, 465, 466, 467, 468, 469, 470, 471, 472, 473, 474, 475, 476, 477, 478, 479, 480, 481, 482, 483, 484, 485, 486, 487, 488, 489, 490, 491, 492, 493, 494, 495, 496, 497, 498, 499, 500, 501, 502, 503, 504, 505, 506, 507, 508, 509, 510, 511, 512, 513, 514, 515, 516, 517, 518, 519, 520, 521, 522, 523, 524, 525, 526, 527, 528, 529, 530, 531, 532, 533, 534, 535, 536, 537, 538, 539, 540, 541, 542, 543, 544, 545, 546, 547, 548, 549, 550, 551, 552, 553, 554, 555, 556, 557, 558, 559, 560, 561, 562, 563, 564, 565, 566, 567, 568, 569, 570, 571, 572, 573, 574, 575, 576, 577, 578, 579, 580, 581, 582, 583, 584, 585, 586, 587, 588, 589, 590, 591, 592, 593, 594, 595, 596, 597, 598, 599, 600, 601, 602, 603, 604, 605, 606, 607, 608, 609, 610, 611, 612, 613, 614, 615, 616, 617, 618, 619, 620, 621, 622, 623, 624, 625, 626, 627, 628, 629, 630, 631, 632, 633, 634, 635, 636, 637, 638, 639, 640, 641, 642, 643, 644, 645, 646, 647, 648, 649, 650, 651, 652, 653, 654, 655, 656, 657, 658, 659, 660, 661, 662, 663, 664, 665, 666, 667, 668, 669, 670, 671, 672, 673, 674, 675, 676, 677, 678, 679, 680, 681, 682, 683, 684, 685, 686, 687, 688, 689, 690, 691, 692, 693, 694, 695, 696, 697, 698, 699, 700, 701, 702, 703, 704, 705, 706, 707, 708, 709, 710, 711, 712, 713, 714, 715, 716, 717, 718, 719, 720, 721, 722, 723, 724, 725, 726, 727, 728, 729, 730, 731, 732, 733, 734, 735, 736, 737, 738, 739, 740, 741, 742, 743, 744, 745, 746, 747, 748, 749, 750, 751, 752, 753, 754, 755, 756, 757, 758, 759, 760, 761, 762, 763, 764, 765, 766, 767, 768, 769, 770, 771, 772, 773, 774, 775, 776, 777, 778, 779, 780, 781, 782, 783, 784, 785, 786, 787, 788, 789, 790, 791, 792, 793, 794, 795, 796, 797, 798, 799, 800, 801, 802, 803, 804, 805, 806, 807, 808, 809, 810, 811, 812, 813, 814, 815, 816, 817, 818, 819, 820, 821, 822, 823, 824, 825, 826, 827, 828, 829, 830, 831, 832, 833, 834, 835, 836, 837, 838, 839$

FIGURE 33



Y-SCALE = 5.00E+01 UNITS/INCH

X-SCALE = 5.00E+01 UNITS/INCH

GENTZ 3D RMS SMOOTHING RESULTS RUN 3A

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66-585

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Thesis

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c.1

Investigation of optimum smoothing in a track-while-scan radar using three dimensional simulation.

Thesis

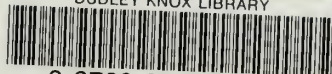
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